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MODELING HABITAT SUITABILITY AND LANDSCAPE RESISTANCE FOR
MEADOW JUMPING MICE IN THE WESTERN GREAT PLAINS

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ABSTRACT:

Since Preble's Meadow jumping mouse (*Zapus hudsonius preblei*) was first listed as a threatened species under the Endangered Species Act, there has been controversy over its taxonomic status as a unique subspecies. Some researchers believe *Z. h. preblei* is actually a subpopulation of a neighboring subspecies, the Bear Lodge Meadow jumping mouse. (*Z. h. campestris*). If this were found to be the case, *Z. hudsonius* might not require federal protection in the state of Wyoming and the restrictions on land use and development for private landowners could be lifted. The goal of this study was to identify suitable habitat patches capable of supporting intermediate populations of *Z. hudsonius*, which could facilitate gene flow between the two populations. A shared gene pool could indicate the two populations are not distinct subspecies. Geographic Information Science (GIS) was used to model the suitability of habitat in the region between the known ranges of *Z. h. preblei* in southeast Wyoming and *Z. h. campestris* in western South Dakota. Five primary habitat suitability models were generated based on literature review and expert opinions using ArcGIS 9.3 and the Corridor Design Toolkit. Of these models, three showed significant patches of suitable habitat within the analysis area, suggesting portions of the analysis areas could potential support intermediate populations of *Z. hudsonius*. Two key areas of higher suitability were identified, which should be further evaluated to determine if intermediate *Z. hudsonius* populations are actually present at these locations.

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I. INTRODUCTION:

A. General Introduction:

Two subspecies of Meadow jumping mice (*Zapus hudsonius*) currently inhabit this region of eastern Wyoming and western South Dakota: the Preble's Meadow jumping mouse (*Z. h. preblei*) found in the Laramie Mountains and the Bear Lodge Meadow jumping mouse (*Z. h. campestris*) found in the Black Hills. *Z. h. preblei* was listed under the Endangered Species Act of 1973 (ESA) as threatened throughout its range in Wyoming and Colorado. In 2008, the species was delisted for the state of Wyoming, but its listing had resulted in a large controversy between the federal government and private landowners. Some organizations and private citizens felt their rights were being unnecessarily restricted to protect a subspecies that might not need federal protection. Other groups and federal officials supported protection for *Z. h. preblei* as a unique subspecies in danger of extinction throughout its range. Part of this controversy revolved around the genetic uniqueness of *Z. h. preblei* and whether it was truly distinguishable from the nearby subspecies, *Z. h. campestris*. If these two subspecies are actually populations of the same subspecies than the federal protection could prove unnecessary and the restrictions on private landowners could be lifted. However, attempts to directly measure the genetic and physical variation between the two subspecies to determine their taxonomic uniqueness has been as controversial as the management.

The current study takes a different approach towards addressing the taxonomic controversy surrounding *Z. h. preblei* by examining the potential for gene flow between the two populations by means of possible intermediate populations in the area between

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southeastern Wyoming and western South Dakota.   As this area has not been extensively

studied for the presence of *Z. hudsonius*, habitat suitability modeling was used to assess the

possible existence of habitat patches capable of supporting such intermediate populations.

Geographic Information Science (GIS) was used to model potential habitat suitability in the

region and identify key areas which should be targeted for future studies of the distribution

and status of *Z. hudsonius* in the Western Great Plains.

B. The Problem:

The original listing of *Z. h. preblei* in 1998 resulted in a controversy involving federal,

state and local governments, non-governmental organizations, and private landowners.

Many of these stakeholders hold very strong opinions regarding the management and

protection of *Z. h. preblei*. These opinions are based in environmental, social, economic

and political values and have important consequences for the conservation and

management of *Z. h. preblei*. The controversy and debates surrounding Preble's Meadow

jumping mouse largely revolve around a single question: Is *Z. h. preblei* truly a separate

subspecies distinguishable from the nearby subspecies *Z. h. campestris*?

Krutzsch (1954) originally identified *Z. h. preblei* as a separate subspecies

distinguishable from *Z. h. campestris* based on differences in skull measurements and fur

coloration. However, this distinction was based on a study of only four skulls and 11 skins.

Several subsequent studies have failed to find any physical features that could reliably be

used to differentiate between *Z. h. preblei* and *Z. h. campestris* (Ramey et al. 2005). This

discrepancy led to the use of genetics as a means of testing the taxonomic validity of these

two subspecies. Two major genetic studies of *Z. h. preblei* and *Z. h. campestris* have been

undertaken in an attempt to determine if there are significant genetic differences between

these two populations, supporting their status as separate subspecies: Ramey et al. (2005) and King et al. (2006).

Ramey et al. (2005) tested first for a significant difference in physical characteristics between *Z. h. preblei* and *Z. h. campestris* using forty skulls of each subspecies. Finding no significant morphological differences between the two subspecies, they attempted to distinguish the two subspecies genetically. They based the analysis on the principle that if these groups were separate subspecies, they would expect to find greater genetic variation between the subspecies than within each. They found no discernible genetic differences between *Z. h. preblei* and *Z. h. campestris* or *Z. h. intermedius* which is also found in the region. They concluded these "subspecies" should all be regarded as population segments of a single subspecies *Z. h. campestris* According to their work, *Z. h. preblei* is not a separate subspecies and should not be treated as such with regard to management decisions (Ramey et al. 2005).

Almost immediately after this work was published, a petition was created by the state of Wyoming to delist *Z. h. preblei* from the ESA based on this new information. This petition led to debates and a follow-up study was commissioned by US Geological Survey (USGS) to confirm the conclusions of Ramey et al. (2005) and further the genetic analysis of *Z. hudsonius.* King et al. (2006) conducted an independent DNA study of *Z. hudsonius* in Wyoming, focusing on *Z .h. preblei*, *Z. h. campestris* and *Z. h. intermedius*. They examined both fresh tissues and museum skins, two different (and longer) sections of mitochondrial DNA and 20 different loci in the nuclear DNA. These were tested for number of distinct alleles per loci for each population. King et al. (2006) not only found noticeable genetic differences between each population for the new loci, but also found

variation in loci used by Ramey et al. (2005). Far from answering the original question and settling the debate, these conflicting results served only to complicate an already complex and sensitive situation.

The general public is equally divided. Those groups in favor of protecting *Z. h. preblei* also support the subspecies status of *Z. h. preblei* and *Z. h. campestris* and the work of King et al. (2006). These include Biodiversity Legal Foundation, Defenders of Wildlife, and The Nature Conservancy. However, many of these groups have secondary political objectives as well. The president of Biodiversity Legal Foundation, stated the larger issue behind the group's petition to list *Z. h. preblei* as an endangered species. He stated, "[This] is about the destruction of riparian corridors from Cheyenne to Colorado Springs" (Crifasi 2007:515). In this scenario, *Z. h. preblei* is being used as a proxy for a much larger environmental issue: the destruction of riparian corridors as a result of increasing urbanization. Other stakeholders are against the federal protection of *Z. h. preblei* largely because of the social and economic costs associated with a listed species. These stakeholders, who include private landowners, ranchers and developers continue to support the conclusions of Ramey et al. (2005) and regard *Z. h. preblei* as another population of *Z. hudsonius*. Both groups of stakeholders continue to cling strongly to their own opinion and the evidence supporting that opinion. As a result, the protection and management of *Z. h. preblei* remains controversial in the Western Great Plains.

The controversy over the genetic distinctions between *Z. h. preblei* and *Z. h. campestris* stems from the lack of a clearly defined cut-off point for the amount of genetic variability which must be exhibited for a population to be declared a separate subspecies. One definition used for subspecies is a population on a separate evolutionary trajectory (Coyne

and Orr 2004). But how much of a genetic difference is required for a population to be considered on a separate evolutionary course from the rest of the species? And how should this genetic difference be measured? These questions are not easy ones to answer and in fact, the answers might well be different for different organisms. However without an agreement on the required genetic diversity, the controversy over the taxonomic status of *Z. h. preblei* is not likely to be resolved in the near future.

C. A Different Approach:

Another approach towards addressing the taxonomic controversy surrounding *Z. h. preblei* is to consider the potential for movement of genetic information between populations rather than focusing on the existing genetic variation between them. This method is less easily quantified and harder to test, but would not require a decision as to how large of a genetic difference is needed to be considered on a separate evolutionary trajectory. By this approach, *Z. h. preblei* and *Z. h. campestris* would be considered as separate subspecies, if there was no active exchange of genetic material between the populations. If so, *Z. h. preblei* and *Z. h. campestris* would be considered two unique subspecies. As such, they could be subject to different management practices and deserving of separate conservation statuses. If genetic information is being exchanged between the two populations, it would suggest the two populations are not on separate evolutionary trajectories and might best be considered a single subspecies.

The question now becomes whether or not there exists the potential for gene flow between the populations. The currently recognized ranges of *Z. h. preblei* and *Z. h. campestris* are separated by > 150 km (Ramey et al. 2005) making it highly infeasible a single individual could move from one population to the other. Thus, these two

populations are currently considered to be geographically isolated. However, genetic

information could potentially move from one population to the other by means of multiple

intermediate populations in the intervening region. Whether such intermediate populations

exist or could exist is currently unknown. Most of the studies of *Z. h. preblei* have focused

on the known populations found in southeastern Wyoming and northern Colorado, not in

the northeastern portions of Wyoming. *Z. h. campestris* has not been extensively studied

and most of the information concerning the distribution and habitat associations of this

subspecies has come from general small mammal trapping surveys conducted in the Black

Hills area by the University of Kansas (Beauvais 2000; Rinker, G. personal

communication). The region between these areas (Figure 1) has not been directly surveyed

for the presence of any Meadow jumping mice. *Z. hudsonius* are typically shy and

inconspicuous, meaning there could be individuals living in this area that have never been

documented.

Figure 1. Geographic area of interest between the ranges of *Zapus hudsonius preblei* in the Laramie Mtns, WY (Yellow) and *Zapus hudsonius campestris* in the Black Hills, SD (pink). Analysis area outlined in red. Data from accessed from Wyoming Natural Diversity Database (2009), University of Kansas (2009) and South Dakota Game Fish and Parks (2011). [adapted from: Google Maps].

D. Study Objectives:

The current study attempts to determine if genetic exchange could be occurring between the two populations of *Z. hudsonius* in eastern Wyoming and western South Dakota by assessing the suitability of habitats in the area. In the context of this study, *Z. hudsonius* refers to individuals belonging to either subspecies: *Z. h. preblei* or *Z. h. campestris.*

For genetic information to be moving between the two recognized populations, three criteria must be met:

1. Intermediate populations have to exist in the region between the known ranges of *Z. h. preblei* and *Z. h. campestris* (termed the analysis area)
2. Individual meadow jumping mice have to be moving between populations
3. Intermediate populations must be separated by less than the maximum dispersal distance of *Z. hudsonius* to provide contiguous coverage across the analysis area

The current study focuses on the first criterion, searching for areas of potentially suitable habitat in the analysis area that could potentially support intermediate populations of *Z. hudsonius*. The objectives were two-fold:

- To analyze the region between the known population ranges of *Z. h. preblei* and *Z. h. campestris* to determine if potentially suitable habitat is present.

- To identify key areas of potentially suitable habitat in this region which could be studied to determine the existence of intermediate *Z. hudsonius* populations

A GIS was used to model the potential suitability of the landscape based on factors identified as important in determining suitability of habitat for *Z. hudsonius*. Literature review and expert input were used to develop a series of models showing the potential suitability of the region. These models were then compared to each other and spatially overlaid to isolate key areas of interest.

II. BACKGROUND

A. Biology of Meadow Jumping Mice:

Jumping mice (*Zapus sp.*) are small rodents native to North America. They are tan or buff colored often with a darker dorsal strip. They have a long tail which comprises approximately 60 percent of the total body length and large, powerful hind feet (USFWS 1998). These feet allow the mouse to evade predators by taking large, bounding leaps of up to .6 m, resulting in the jumping portion of the name.

Preble's Meadow jumping mouse (*Zapus hudsonius preblei)* is one of 12 recognized subspecies of *Z. hudsonius* found in North America. *Z. hudsonius* was first documented in 1889 by Preble, who also identified a subspecies of *Z. hudsonius*: The Bear Lodge Meadow jumping mouse (*Z. h. campestris*). Krutzsch (1954) revised the taxonomy of *Zapus* to recognize three living species in the genus including *Z. hudsonius*. At the same time, Krutzsch designated *Z. h. preblei* as a separate subspecies, taxonomically distinct from *Z .h. campestris* (USFWS 1998). The two subspecies are also considered to be geographically isolated. *Z .h. campestris* occupies a limited range in the Black Hills region of South Dakota and eastern Wyoming (Cryan 2005). *Z. h. preblei* is found in eastern Colorado and southeastern Wyoming. In Colorado, *Z. h. preblei* is currently found in

Boulder, Jefferson, Douglas, El Paso, Weld, Larimer and Elbert counties. In Wyoming, its range is restricted two counties: Laramie and Albany. (USFWS 1998)

Z. h. preblei is a riparian species occupying areas surrounding streams, wetlands and even irrigation ditches, occasionally venturing into drier upland areas for foraging and hibernation. Preferred habitat includes a dense understory with a high diversity of shrub species (Keineth, 2001). Species such as willows (*Salix spp*.), alders (*Alnus spp*.) and currants (*Ribes spp*.) are commonly associated with favorable habitat. The diet of *Z. h. preblei* varies slightly with the seasons, consisting of insects and fruits in the spring and early summer, and switching to be predominately seed based in late summer and early fall as the mouse prepares for hibernation. Hibernation generally occurs from September until May depending on the weather and the weight of the individual (Quimby 1951). Little is known about the natural history of *Z. h. campestris* beyond the fact it too is a riparian species. However, it is believed to have similar habitat preferences and behavior to *Z. h. preblei* (Beauvais 2000).

B. History of *Z. hudsonius* in the Western Great Plains:

In 1994, Biodiversity Legal Foundation, a Colorado non-governmental organization (NGO) petitioned the US Fish and Wildlife Service (USFWS) to list *Z. h. preblei* as an endangered species under the Endangered Species Act of 1973 because the population was suffering a steep decline. In March of 1997, USFWS issued a follow-up to the petition reviewing their findings and formal proposal to list *Z. h. preblei* as an endangered species in the states of Colorado and Wyoming. In May 1998, USFWS listed *Z. h. preblei* as a threatened species (USFWS 1998). However, critical habitat for the species was not designated until five years later in 2003 because not enough was known about the habitat

preferences of *Z. h. preblei*. It was determined that more research would be necessary before critical habitat could be effectively managed for the benefit of the species (USFWS 1998).

The primary reason for listing *Z. h. preblei* as an endangered species was habitat loss due to the expansion of human activities and development into *Z. h. preblei* habitat and the destruction of the riparian and wetland habitats preferred by the mouse. Conversion of grasslands to farms and overgrazing might have contributed to the decline of *Z. h. preblei* by limiting the food supply needed to prepare for extended hibernation. Water management practices, including damming and the diversion of streams for irrigation have reduced the amount of suitable habitat present in the region. Secondary reasons for the listing included an already small population size and the lack of other protections for either the mouse or its habitat. (USFWS 1998).

In 2003, the State of Wyoming's Office of the Governor and Coloradans for Water Conservation and Development both petitioned the federal government to remove *Z. h. preblei* from the endangered species list because new research by Ramey et al. (2005) suggested *Z. h. preblei* was genetically indistinguishable from *Z. h. campestris*. In 2008, USFWS made the decision to delist *Z. h. preblei* in the state of Wyoming, but keep its protected status in Colorado. Contrary to the initial delisting proposal, the species was delisted, not because of an error in taxonomic designation as was originally proposed, but because more recent research suggested the Wyoming population was both larger than originally estimated and less threatened by habitat loss and development (USFWS 2008).

C. Previous Studies:

Previous studies of *Z. hudsonius* in the Midwest have focused of the subspecies *Z. h. preblei* as an organism of national conservation concern. Since *Z. h. preblei* was listed as federally threatened species in 1998, it has received nationwide attention and scientific interest. Multiple studies have been conducted on the population status and habitat requirements of *Z. h. preblei*. Some of these studies have also included neighboring subspecies of *Z. hudsonius* to gain a better understanding of the overall ecology of the species. Of particular relevance to the current study is a study conducted in 2004 by the Wyoming Natural Diversity Database (WYNDD 2004). Biologists from WYNDD used GIS to extrapolate habitat preferences of *Z. hudsonius* based on known presence and absence locations. They then applied the derived model to the entire state to determine other areas of potential habitat in Wyoming. The WYNDD study differed from the present study in two important regards: it used a different method of identifying important habitat characteristics and it was geographically restricted to Wyoming.

The WYNDD study started with known suitable habitats and used the characteristics of these areas to identify other areas with similar habitat characteristics. For the present study, the key characteristics of suitable habitat were identified first, and used to generate habitat suitability models. These models were then compared to known capture records to assess the accuracy of the models. This method allowed for the better use of categorical spatial data and avoided` the assumption that areas where *Z. hudsonius* have not been trapped are unsuitable. Using literature and expert input as the basis for determining habitat suitability increased the variability in the modeling, but also made it more difficult to quantify the results. Another major difference in methodology between the two studies

that could be contributing to the difference in results was the inclusion of elevation in the WYNDD study. Elevation was excluded from the present study because elevation values considered suitable for *Z. hudsonius* in the primary literature encompassed almost the entire study area. However, since most of the data points used in the WYNDD occurred at a smaller range of elevations (The Bighorn and Laramie Mountains) the elevations derived from these data points may have excluded some of the low lying areas from being deemed suitable.

This second difference, the geographic restriction of the study to Wyoming, broaches a larger debate in wildlife management in the United States, which concerns the fact many of our species are managed on a state by state basis. It is a well accepted fact organisms and populations are not restricted by political boundaries such as state borders.   Management decisions made by one state will also affect the populations in other states.

This issue of studying populations and making management decisions based on such arbitrary boundaries has recently become very contentious. In 2009, USFWS made the decision to delist the Rocky Mountain population of the Gray wolf (*Canis lupus*) from the ESA in the states of Idaho and Montana, removing many of the federal restrictions regarding the take and transport of wolves. However, the wolf retained its endangered status in the state of Wyoming on the grounds that "the Wyoming portion of the range represents a significant portion of range where the species remains in danger of extinction because of inadequate regulatory mechanisms" (USFWS, 2009). USFWS was concerned that Gray wolf management plans developed by the state of Wyoming were overly aggressive and could jeopardize the continued presence of the wolves in the state.

This issue was brought before the District Court of Montana by multiple non-governmental organizations who were concerned about the precedents would be set for wildlife management as a result of the decision to delist the Gray wolf only in some states within it range. In 2010, the Court of Montana reversed the decision to delist Gray wolves in Montana and Idaho and reinstated their protected status. The court ruled the decision did not comply with the ESA, which did not allow only part of a distinct population segment to be listed, in this case the part of the population in Wyoming. (DOW, et al. v. Ken Salazar, et al. 2010). Meadow jumping mice became involved in this debate when biologists pointed to the case of *Z. h. preblei* as a precedent for delisting species based on state boundaries. The court rulings associated with the Grey wolf controversy could lead to the reversal of the delisting of *Z. h. preblei*, causing its protected status to be reinstated in the state of Wyoming (Estes-Zumpf, personal communication). If *Z. h. preblei* is relisted as an endangered species, the controversy over its management and taxonomic status will be reignited.

The present study explores a new approach for addressing the controversial taxonomy of *Z. h. preblei* and will hopefully identify directions for future research to facilitate management decisions.

III. MATERIALS AND METHODS

A. Overview

Habitat suitability throughout the analysis area was determined by combining the suitability of individual habitat factors. Factors for this analysis were chosen based on habitat preferences of *Z. hudsonius,* known influences on the dispersal characteristics of small rodents and availability of relevant data. Three habitat factors were selected for inclusion in the analysis as listed below.

- Vegetation type

- Distance from water

- Distance from nearest road

For each factor, a suitability grid was developed covering the relevant study area by assigning a suitability value to each grid cell in the analysis area based on the attributes of each cell. The dataset for each factor was divided into discrete categories which were assigned a value from 1 to 10, with 1 being the highest suitability. The relevant study area is defined as the area between the known capture locations of both subspecies. These ranges were defined based on recordings and sightings of *Z. h. preblei* and *Z. h. campestris* in Wyoming and South Dakota over the past 50 years. Factor datasets were clipped to the relevant study area to facilitate analysis. Each factor was also assigned a specific weight based on the perceived importance of each in determining the suitability of habitat for *Z. hudsonius.* Data preparation and the final least cost analysis were conducted in ArcGIS 9.3 using the Spatial Analysis Tools and Corridor Designer Tools. Corridor Designer is a suite

of tools developed by the Arizona Missing Linkage project team for modeling wildlife corridors, areas of connected habitat through which animals regularly move. The Corridor Designer Tools allows for the inclusion of additional biological factors such as dispersal distance and home range size in the model (Majka et al. 2007).

Habitat preferences of *Z. hudsonius* were derived from a review of available literature, which were then used to select habitat factor datasets for inclusion in the models. Suitability values were derived from the literature review and expert opinions obtained through an email survey. Data on known capture locations and sightings of *Z. hudsonius* were obtained from state and university records. The habitat factor and location datasets were analyzed and combined in ArcGIS to develop habitat suitability models for the analysis area. These steps are discussed in more detail below.

B. Review of Literature on Habitat Factors:

A review of the available literature on the habitat preferences and behavior of *Z. hudsonius* was used to develop estimates of suitability for each category within the three habitat factors as well as an understanding of the dispersal ability and territory size of *Z. hudsonius*.

1. Vegetation Characteristics:

Z. hudsonius exhibit a strong preference for riparian vegetation. They are often found along riparian corridors in vegetation communities comprised of willows, alders and cottonwoods. They prefer communities with a diversity of shrub species mixed with a few trees and an herbaceous understory. Other common species associated with riparian corridors and ideal *Z. hudsonius* habitat include: birch

(*Betula spp.)*, mountain mahogany (*Cercocarpus spp.)*, Snowberry (*Symphoricarpos occidentalis*), wild rose (*Rosa woodsii*), currants, forbs, and grasses (Schorr et al. 2009). *Z. hudsonius* are also present in the drier upland areas surrounding these riparian patches including Ponderosa pine (*Pinus ponderosa)*, White spruce (*Picea glauca)*, and Bur oak (*Quercus macrocarpa*) forests. Again, *Z. hudsonius* appear to exhibit a preference for areas with a shrub layer, which in these areas is often comprised of Chokecherry (*Prunus virginiana*), Gambel oak (*Quercus gambelii*) and sage (*Artemisia spp.)* (Schorr 2009).

Higgins et al. (1997) ranked these habitats in order of preference exhibited by *Z. hudsonius*. They ranked wetlands as the most preferred habitat followed by grasslands, cropfields and forests (Higgins et al 1997), but this ranking might be over generalized. Riparian corridors or wetlands are clearly the preferred habitat for *Z. hudsonius* and there is a large volume of evidence suggesting grasslands are also commonly used by *Z. hudsonius*. Agricultural fields, for crops such as wheat, tend to have many of the same properties as wild grasslands with regard to cover and food availability. However, Zwank et al. (1997) found significantly lower capture rates in croplands than in neighboring wetlands and then only in one type of cropland (clover). These results are specific to *Z. h. luteus,* which is not found in the area of interest, but they suggest a lower preference for croplands and habitat suitability of croplands might be dependent on the type of crop being grown. Due to limited information available in the literature, studies of other subspecies such as *Z. h. luteus*, with the assumption that *Z. h. preblei* and *Z. h. campestris* would exhibit similar preference. However, there may be differences in vegetation

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preferences among subspecies. There is evidence to suggest that *Z. h. campestris* in the Black Hills is more commonly found in coniferous forests than *Z. h. preblei*. *Z. h. campestris* has been captured in open coniferous forests, drier wooded slopes and dry meadows (Cryan 2005).

In all vegetation systems, *Z. hudsonius* shows a preference for diverse vegetation communities with a wide variety of species and a mix of all three structural stages, herbs, trees and especially shrubs. *Z. hudsonius* abundance showed a slight positive correlation with shrub density and a possible negative correlation tree density (Schorr 2001).

2. *Distance from Water:*

Z. hudsonius are closely tied to the presence of water. *Z. hudsonius* is commonly considered a riparian species found near rivers and permanent streams. However, they have been found near small lakes and ponds, marshes and wetlands and even irrigation ditches. In at least one instance, *Z. h. preblei* was found along the banks of a stream, which was not actively flowing where the only water source was a handful of stagnant pools. The type of water body present may be less important than the perennial presence of water, which is likely tied to soil type and vegetation. (Bureau of Reclamation 2009).

Day use nest of *Z. h. preblei* have been found up to 175 m from a body of water, but were most commonly within 30 m (Bain and Shenk 2002). Zwank et al. (1997) recorded individual *Z. h. luteus* over 110 m from a permanent water source. A telemetry study of *Z. h. preblei* found they would often move an average of 35 m

from a stream with a maximum perpendicular movement of 150 m (Keinath 2001). The largest average distance from stream center reported was 215 m observed during a telemetry study (Meaney et al. 2003).

The average distance to water may even be dependent on other factors as studies of the same site in consecutive years have had very different results. Schorr (2001) reported a mean distance from a creek of 11.5 m in 1998 and a mean distance from a creek of 50.5 m in the following year at the same location.

3. *Distance from Roads:*

Roads were considered with regard to two factors. Distance from the nearest road was used as a proxy for human disturbance. Secondly, the roads were considered to serve as a filter for the dispersal of *Z. hudsonius*, in that they would limit, but not prevent movement. These two factors were combined in the final suitability grid, but are addressed separately here.

Roads as a measure of human disturbance

Distance from roads was used as a measure of human activity in an area. An area in close proximity to a road is likely to have more human activity and disturbance than a more distant area (Beier et al. 2007). The impacts of human activities on *Z. hudsonius* are not well-defined, so more emphasis was placed on the impact of the roads themselves. Several researchers have proposed that wildlife are discouraged from residing or venturing in close proximately to roads due to the noise, vibrations, smell, etc. caused by traffic. This behavior is termed the road edge effect. This effect differs for different species. Some species have shown a

preference for the cleared habitat bordering the road, while others avoid this open habitat (Beier et al. 2006).

Road as a filter

The road itself can also affect the movement of organisms, either as a barrier, completely blocking movement or as a filter, reducing the number of animals moving between adjacent areas but not completely stopping movement. The magnitude of this filter effect is dependent on the affected species and width of the road. Not all species are willing to cross a road and even those species which do cross do so in much smaller numbers. The width of the road has a noticeable impact on animal movements, especially for small mammals. A study of road effects on small mammals by Yale Conrey and Mills (2001) showed only 10% of *Peromyscus spp*. crossing a two-lane highway and only 3% crossing a four-lane highway. They also observed a Western jumping mouse (*Z. princeps*) crossing a two-lane highway indicating *Zapus* will cross roads if only infrequently (Yale Conrey and Mills 2001). These observations support the idea of roads as a filter instead of a barrier to *Z. hudsonius* movement.

For the present study, I assumed *Z. hudsonius* would respond to roads in a manner similar to that exhibited by *Peromyscus spp.* since there was no literature found on the effects of roads on *Z. hudsonius. Peromyscus spp.* show similar habitat preferences to *Z. hudsonius* with both preferring shrubby habitat often along streams or marshes. Both are associated with similar shrub and tree species and are

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known to forage in grassy habitat. However, *Peromyscus spp.* may be more of habitat generalist than *Z. hudsonius*.

4. *Movement and Dispersal:*

Z. hudsonius have two peak breeding times, one in late May - early June and one in late July, in some areas a third breeding peak occurs in mid-August. It takes approximately 4 weeks for the young to mature at which time they will disperse from the nest site and establish new home ranges. Dispersal usually peaks during July and August. By September, movement ceases as individuals prepare to enter hibernation (Quimby 1951).

The distance an individual jumping mouse will move during the course of its daily activities or when attempting to establish a new territory is uncertain. Radio-collar studies have recorded average movements of individuals of approximately 526 m over a 30 day period with a maximum recorded distance of over 1610 m (Meaney et al. 2003). These larger movements usually occur along a stream, rather than away from it. Mark-recapture studies of jumping mice in Colorado have documented individuals moving over 4300 m (Schorr 2003). A separate telemetry study found the average distance a mouse would move away from a stream to be about 35 m with a maximum movement of only 150 m (Keinath 2001). Schorr (2001) had similar results with a maximum distance from a creek of 144 m.

5. *Home range and breeding patch size*

Schorr (2003) reported a mean home range size of 1.41 ± 1.31 ha on one study site in Colorado. This area is assumed to be similar the size of the territory needed

to support a single breeding pair of *Z. hudsonius*. No information was found in the literature regarding the minimum area of habitat needed to support a small population.

C. Selection of Factors:

A total of three factors were chosen for use in the model. Selection was made based on the importance of the factor in determining habitat suitability, the availability of information on the preferences of *Z. hudsonius* with regard to that dataset and the availability of quality spatial datasets for the area of interest. Originally, vegetation type, vegetative cover, distance from water and distance from roads were selected as factors and included in the expert surveys. However, vegetative cover had to be removed from the final analysis due to difficulties in the dataset[1]. Topology, soil type and slope were eliminated due to a poor understanding of their impact on suitability of habitat for *Z. hudsonius*; little to no information was present in the available literature on the selection for or avoidance of any of these habitat characteristics. Elevation was eliminated from the analysis because the range of suitable elevation values for *Z. hudsonius* encompassed a vast majority of the study and it was deemed there was no benefit to including it in the analysis for this particular study area. Human population density was replaced by distance from roads as a measure of human activities and impact.

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[1] Originally, the LANDFIRE Vegetative Cover dataset was included as a factor. However, this dataset only included vegetative cover data for areas classified as forest, shrub or herbaceous in the vegetation type dataset. The remaining areas would have had to be removed from the analysis or reuse the suitability values from the vegetation type dataset.

The selected factors and the dataset used for each are as follows:

1. *Vegetation Type:*

   Existing Vegetation Type (EVT) from the National LANDFIRE Dataset (USGS)

   The LANDFIRE Dataset was selected as the most complete set of vegetation data available for the region of interest. The LANDFIRE version 1.0.2 was selected as the most recent and update version of LANDFIRE for the contiguous US. National Landcover Dataset was considered, but rejected because LANDFIRE EVT had a more detailed breakdown of vegetation categories. The dataset was derived from remotely sensed LANDSAT data and classified into categories according to the NatureServe terrestrial ecological systems classification. (<http://www.natureserve.org/publications/usEcologicalsystems.jsp>).

2. *Distance from Water:*

   National Hydrography Dataset (USGS)

   The National Hydrography Dataset (NHD) was chosen to ensure continuity among the data across state boundaries. The NHD also offered the opportunity to select some features based on their status as ephemeral, intermittent or perennial. This feature is highly useful in the area of interest where a large number of waterbodies are seasonal, which impacts their suitability as habitat for *Z. hudsonius*. The waterbodies selected as important to *Z. hudsonius* ecology included streams, rivers, ponds, lakes, marshes/swamps, and springs.

3. *Distance from Roads:*

Census 2000 TIGER/Line® Shapefiles: Roads Layer (ESRI)

TIGER/Line was chosen because it had detailed roads data available for the entire analysis area downloadable by county. It also offered the opportunity to assort roads by size category using the Census Feature Class Codes which separate roads into primary, secondary and local roads.

D. Expert Surveys:

To gather expert knowledge about habitat suitability for the purposes of the current study, various professionals familiar with the ecology and behavior of *Z. hudsonius* were invited to provide their input on the effect of the selected habitat factors on the suitability of habitat and the relative importance of each factor in determining overall habitat suitability

A habitat parameter evaluation survey, modified from previous work by the Arizona Missing Linkages Project (Beier et al. 2006) was generated using MS Excel. This survey was emailed to six different professionals who have published data on habitat ecology of *Z. hudsonius*.

This survey requested each expert to assign a suitability value to each category contained within the three habitat factors. Suitability values ranged from 1 to 10 with 1 being strongly preferred and 10 being strongly avoided. Experts were requested to weight each factor based on its relative importance to overall habitat suitability, with all weights summing to 100. Each expert was asked to provide estimates for dispersal distances and

home range size for *Z. hudsonius*. Citations to justify selections were requested, but optional.

I also completed a copy of the parameter evaluation survey (Appendix A), using information from the literature review to generate my own suitability values, factor weights etc.

The results of these surveys were compiled and compared to determine which categories exhibited noticeable differences in opinion between the various participants. For the vegetation type factor, Spearman's rank correlation coefficient was used to compare the similarities between the suitability values assigned by each of the five participants. Statistical analysis was performed using the program R (R Development Core Team). Simple visual comparisons and analysis were used for the other categories.

E. Zapus Location Data:

Records of *Z. hudsonius* sightings and captures were gathered from several university collections and state records. These sources include South Dakota Game Fish and Parks (SDGFP), WYNDD, University of Kansas and University of Nebraska. Records were compiled and filter to only those with specific locations, a positional accuracy of < 6 miles for South Dakota records or < 700m for Wyoming data, and a datum present. Records from *Z. hudsonius preblei, Z. h. campestris* and *Z. h. intermedius* were all included. As the goal of this study is to assess the possibility of any *Z. hudsonius* living in the analysis area, it was not necessary to discriminate based on subspecies.

All *Z. hudsonius* records meeting these criteria were plotted in geographic coordinates on a map of the region using ArcMap (ArcGIS, ESRI). For the WYNDD data, it was necessary to first convert the location data from Public Land Survey System units

(township, range and section) to standard geographic coordinates (latitude and longitude). This conversion was performed using the Township Geocoder tool, an online conversion program run by the Department of the Interior's Bureau of Land Management (www.geocommunicator.gov). Once all data points were plotted in ArcMap, shapefiles were manually digitized around these data points to represent the approximate range of the Black Hills and Laramie mountain populations of *Z. hudsonius*.

F. **GIS Analysis:**

GIS Analysis consisted primarily of four stages: (1) pre-analysis data preparation and reclassification, (2) habitat suitability modeling using Corridor Designer Toolkit, (3) model comparison through visual analysis and spatial overlay of resulting models.

1. *Data Preparation and Reclassification*

All datafiles had to be processed and manipulated prior to their use in modeling and analysis. All datafiles were projected in NAD 83 UTM 13N and clipped to the analysis area to facilitate data processing.

Vegetation Type

The original data for the vegetation type from the LANDFIRE Existing Vegetation Type dataset was simplified to reduce the number of categories needing to be assigned suitability values. The dataset was derived from remotely sensed LANDSAT data and classified into categories according to the NatureServe terrestrial ecological systems classification. Using the information from NatureServe, the 91 categories of vegetation systems found in the original

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dataset were reclassified into 33 new landcover categories based on the Society of American Foresters (for trees and shrubs), Society for Range Management (for grasslands) and LANDFIRE (other landcover) designations. Descriptions of the 33 categories appear in Appendix B These were further grouped into 10 broader categories based roughly on National Landcover Dataset categories. A table of the 91 original categories grouped into the new classes and subclasses appears in Appendix C.

Distance from Water

Relevant water features were extracted from the NHDs by their temporal designation. Water features included in this study included streams, rivers, ponds, lakes, spring, seeps and swamps. These selected features were further filtered to include only perennial water features. These water features were merged by feature class (point, line or polygon). For each feature class, a distance from water was calculated using the Euclidean Distance tool. Raster calculator was used to calculate the minimum distance from water for each grid cell from the three separate distance rasters. The final output was a raster file of distance from perennial water features relevant to *Z. hudsonius* ecology.

Distance from Roads

Roads data from the National Elevation Dataset for each of the three states were merged into a single shapefile. Distance from roads was then calculated using the Euclidean Distance Tool to create the final distance raster.

2. Habitat Suitability Modeling

Habitat Suitability Models (HSMs) were created using the Habitat Suitability Tool contained within the Corridor Designer Toolkit suite of tools. To create the expert HSMs, the base datasets for each factor were reclassified by the suitability values provide by each expert. The factor weights provided by each expert were also input into the tool to generate the final HSM. The tool offered the option of using either the additive or geometric mean to combine factors in the overall suitability model. For this analysis, the additive mean was used as it provides a more conservative approximation of suitability.

A total of nine models were generated. Five of these models were based on my suitability values combined using different factor weights. These five models were used to gain an understanding of the effect of changing the factor weights on the overall output. Four more models were generated using the suitability values and corresponding factor weights reported by each expert on the parameter evaluation surveys.

3. Comparison of Models

The habitat suitability models generated using the Corridor Designer Tool were compared in two distinct groups. First, the five models generated using the suitability values from the literature review were compared to access the impact of different factor weights. The second group contained the four habitat suitability models generated using the suitability values and factor weights from each expert, plus a representative model chosen from the first five models.

Models were compared both visually and statistically. Visually comparison looked for overall trends in suitability and the amount of variability within the models. The models were also examined for regions that were consistently identified as suitable or unsuitable. The models were then reclassified into four broad suitability categories (Table 1).

Table 1: The four suitability classes used to analyze models and the relation of these to the original 1 − 10 scale used to classify the suitability of each habitat factor for *Z. hudsonius*.

Original Scale	Suitability Levels	
1 - 3	1	Highly Suitable
3 – 5.5	2	Moderately Suitable
5.5 – 8	3	Moderately Unsuitable
8 – 10	4	Highly Unsuitable

The reclassified models were overlaid using ArcMap to determine the percentage of cells having the same classification in both models, different classifications, and drastically different classifications: those cells which differed by more than two categories.

Finally, the top three models were overlaid to identify areas which were classified the same across all three models, which were classified the same in two of three models and which had different classifications in all three models. This analysis was used as a measure of consensus among the models.

IV. RESULTS AND ANALYSIS:

A. Zapus Records:

Records of *Z. hudsonius* captures and observations in eastern Wyoming, western South Dakota and northwest Nebraska were acquired from four sources: The University of Nebraska, University of Kansas, WYNDD and SDGFP. A total of 597 records were compiled and plotted using ArcMap (Table 2). These records are shown by source. These points included records throughout the states of Wyoming, South Dakota, Nebraska and Utah. Originally, records were restricted to those more recent than 1980, but this restriction eliminated all, but 11 of the *Z. h. campestris* records in the Black Hills area. To obtain a larger number of data points, records from 1960 onward were included. Later in the analysis, 11 additional records from SDGFP were added from studies done in 2010. Some of the records from WYNDD had to be eliminated from the data analysis because their locations could not be plotted (ie. "Medicine Bow Nat'l Forest, 38 mi W Centennial"). From the total 597 records, two clusters of points were identified as the two populations of interest, the Black Hills population of *Z. h. campestris* and the population of *Z. h. preblei*. The Black Hills population was comprised of 137 records from   unique locations. The Laramie Mountains population included 48 records from 21 unique locations. The breakdown is shown in Table 3.

Table 2: Records of captures and sightings of the three subspecies of *Z. hudsonius* found in WY, SD and NE sorted by the source of the data: University of Nebraska, University of Kansas, WYNDD and SDGFP.

Data Source	Total Records	Total Records Acquired		
		Z. h. preblei	*Z. h. campestris*	*Z. h. intermedius*
U of Ne	183	0	181	0
U of KS	239	0	121	118
WYNDD	164	148	16	0
SD GFP	11	0	11	0
TOTAL	597	148	329	118

Table 3: Records of *Z. h. preblei and Z. h. campestris* captures and sightings in the analysis area between the Laramie Mtns and the Black Hills as sorted by the source of the data: University of Nebraska, University of Kansas, WYNDD and SDGFP.

Data Source	Total Points	Records in Analysis Area	
		Z. h. preblei	*Z. h. campestris*
U of Ne	0	0	0
U of KS	114	0	114
WYNDD	60	48	12
SD GFP	11	0	11
TOTAL	185	48	137

The age of the observational data used is of some concern. All of the *Z. h. campestris* records from the University of Kansas were collected between 1961 and 1968. These points accounted for 84% of the total *Z. h. campestris* records. The WYNDD data contained 11 *Z. h. campestris* records from the Black Hills of which four were from 1988-1991, three were from 1997, two were from 2002, and one record was from 2004. The 11 records from SDGFP were the most recent coming from 2010. More recent records were available for *Z. h. preblei* due to the studies conducted following its 1998 listing under the

ESA. All of the *Z. h. preblei* records came from WYNDD. 25 of the records were from 1998 and 1999 and 22 were from the 2000s.

From these records, shapefiles were manually digitized to delineate the known range of each population. The approximate range for the Black Hills population covered 7,461 km2 and spanned Custer, Lawrence, Pennington and Meade counties in South Dakota and Crook and Weston counties in Wyoming. The approximate range of the Laramie Mountains population covered 3,925 km^2 and spanned Albany, Converse and Platt counties. The analysis area consisted of a rectangle drawn between the two populations so as to contain at least half of each range. The resulting area covered 52,381 km^2 and spanned Albany, Campbell, Converse, Crook Goshen, Platte, Niobrara, and Weston counties in Wyoming; Custer, Lawrence, Meade and Pennington counties in South Dakota; and Box Butte, Dawes, Scotts Bluff, Sioux and Morrill counties in Nebraska. The approximate population ranges and analysis area are shown in Figure 2.

The closest distance between a *Z. h. preblei* record and a *Z. h. campestris* record was approximately 160 km. Both these records came from WYNDD and were noted as possible breeding areas. The *Z. h. preblei* record was a single female trapped in 1999. The *Z. h. campestris* record was an adult and a juvenile (both male) captured in 2002.

Figure 2: *Z. hudsonius* records in each population by data source. The approximate range of the Black Hills population of *Z. hudsonius* is shown in green and the Laramie Mountain population in orange. The purple rectangle marks the analysis area.

B. Literature Based Suitability Assessment:

This section contains an analysis of the results of the literature review and how this information was converted to suitability values. I completed a parameter estimation survey based on a review of the available literature (Appendix A). These suitability values were in the creation of my five models: Bowe A - E.

Floodplain, Cottonwood-Willow Shrubland and Wet Grasslands were considered to be the most suitable and thus assigned a value of 1. All of these vegetation types have an association with the riparian areas favored by *Z. hudsonius*. Aspen forests, Upper Montane Riparian Gambel Oak Shrubland, Mountain Mahogany Shrubland, Chokecherry-Serviceberry-Rose Shrub and all native grasslands were also ranked as highly suitable habitat (value = 2 - 3) because they contain many of the plant species commonly found at capture locations of *Z. hudsonius*. Moderately suitable habitat (value 4 - 5) contained most of the coniferous forest types, Bur Oak forests, Sagebrush Shrubland, as these habitats are often found adjacent to suitable habitats and might occasionally be used by *Z. hudsonius*. Agriculture and Introduced Herbaceous Vegetation are also in this category because of the preference exhibited by *Z. hudsonius* for diverse vegetation communities and reports of significantly lower numbers of *Z. hudsonius (preblei)* trapped on agricultural lands. Moderately unsuitable vegetative types (value = 6-7) included Spruce-Fir forests, Subalpine Shrubland, Desert Shrub and Developed Low Intensity. The first two types occur primarily at higher elevations and tend to be very dry. The Desert Shrub vegetation type includes potentially adequate shrub cover, but is extremely dry and usually farther from the wet areas preferred by *Z. hudsonius*. The Developed Low Intensity class includes areas with between 20% and 50% impervious surfaces. Alpine, Sparsely Vegetated, Open

Water and Developed Medium Intensity were considered highly unsuitable and thus were assigned values of 8 or 9. The first two classes do not contain adequate vegetative cover to support populations of *Z. hudsonius*, but individuals might be willing to cross these habitats to move between suitable habitats. *Z. hudsonius* cannot live on Open Water, but this land cover class also includes up to 30% of land surrounding the water which may be used by *Z. hudsonius*. Developed Medium Intensity represents a high level of human activity and would be strongly avoided. Barren areas, Snow/Ice and Developed High Intensity areas were assigned a value of 10 as the most unsuitable habitat types.

For distance from water, < 50 m was considered to be the most suitable habitat and assigned a value of 1. Within 200 m of a stream was also considered highly suitable (value = 2) as this is believed to be the distance an individual might travel away from a stream during the course of its normal activities (Schorr 2003). Between 200 – 600 m was considered useable but less preferred with a value of 6. 1,500 m was considered the outer limits of how far an individual would be willing to move away from a stream, but there is a slight possibility that individuals might cross this habitat to reach another stream. Hence, 600 – 1,500 m from water was assigned a value of 8. *Z. hudsonius* are highly unlikely to travel > 1.5 km from a water sources so any further distances were assigned a value of 10.

For distance from roads, within 50 m of a road was assigned a value of 8 to reflect both the strong avoidance of roads exhibited by small mammals and the reluctance of individuals to move across a road. Between 50 and 200 m from a road there is the possibility of a road edge effect occurring, but it would probably not be strong enough to cause *Z. hudsonius* to avoid the area. In assigning this category a value of 5, I was also considering the secondary use of distance from roads as proxy for human activities. At

distances > 200 m from a road, the road has likely ceased to have any negative impact on habitat suitability, hence the assigned value of 1.

C. Expert Surveys:

Parameter estimation surveys were sent to six different experts on *Z. hudsonius* ecology and behavior asking them to estimate suitability values and the relative importance of each factor. Of the six experts asked to participate, one declined, two did not respond and three returned completed surveys. One of the three who responded also referred another expert who completed a survey as well. This amounted to a total of four different expert assessments included in the analysis. I also completed a parameter estimation survey based on a review of the relevant literature adding a fifth assessment to the analysis (Appendix A). These five assessments were compared to each other and my assessment was compared to the four expert assessments. A summary of the results for each category follows:

1. *Factor Weights:*

Each participant was asked to assign a weight to each of the habitat factors representing the relative importance of that factor in determining overall habitat suitability for *Z. hudsonius*. These weights summed to 100. Originally, participants were asked to weight four factors: vegetation type, vegetative cover, distance from water and distance from roads. Most of the participants initially weighted vegetative cover as the most important factor. The elimination of this factor due to problems with the dataset meant all the factor weights had to be adjusted. Three of the four experts were contacted and provided updated values. Expert 1 could not be reached, so the weight assigned to vegetative cover (50) was added to the weight

assigned to vegetation type to represent the overall importance of vegetation. The

new weights assigned by each of the four experts are shown in Table 4. I used a set

of different weights to explore the effect of the factor weights on the overall output.

The weights I used for the five models generated from my suitability values shown

in Table 5.

Table 4: Weights based on relative importance of each factor on determine
habitat suitability for *Z. hudsonius* as assigned by each of the four
experts via parameter evaluation surveys. Factor weights were
required to sum to 100.

	Expert 1	Expert 2	Expert 3	Expert 4
Vegetation Type	60	30	40	30
Distance from Water	40	70	55	60
Distance from Roads	0	0	5	10

Table 5: Weights based on relative importance of each factor on determine
habitat suitability for *Z. hudsonius* as assigned by the author.
These were used to develop five habitat suitability models which
were compared to determine the impact of weightings on the
overall model. Factor weights were required to sum to 100.

	Bowe A	Bowe B	Bowe C	Bowe D	Bowe E
Vegetation Type	55	60	45	50	65
Distance from Water	40	30	45	50	35
Distance from Roads	5	10	10	0	0

Most of the experts ranked distance from water as the most important factor

followed by vegetation type. In some cases these weights were relatively close

(55:40).   In other cases, the weight for distance from water was more than twice the

weight of vegetation type (70:30). In contrast, I ranked vegetation type as more or

equally important to the distance from water. This higher weighting is partially

because I assumed the types of vegetation associated with the riparian areas

preferred by *Z. hudsonius* are more important than the actual presence of water. All participants agreed the importance of distance from roads was minimal with no weight exceeding a value of 10. Indeed, two experts assigned a factor weight of 0 to the distance from roads indicating that roads had no bearing on habitat suitability.

2. *Movement and Habitat Patch Size:*

Dispersal distance represents the distance a single individual will regularly move when establishing a new home range. For the purposes of this study, this value also represents the amount of unsuitable habitat an individual might be willing to cross to reach a new area of suitable habitat. Participants were asked to estimate the standard distance a dispersing individual will move as well as potential maximum movement. The results of the surveys are shown in Table 6. For unknown reasons, one expert declined to complete this section, so only 4 assessments were used.

Table 6: Estimates of dispersal distances (in meters) of *Z. hudsonius* based on expert opinion (Experts 1-4) via parameter estimation surveys and a literature review (Bowe).

	Expert 1	Expert 2	Expert 3	Expert 4	Bowe
Standard Dispersal Distance (m)	N/A	500	500	300	600
Max Dispersal Distance (m)	N/A	5000	1600	3000	4500

Values for standard dispersal distance ranged from 300 – 600 m yielding a mean dispersal distance of 475 m. This value seems to be fairly representative of the overall opinion since two experts estimated standard dispersal distance at 500 m.

Regarding maximum dispersal distance, values ranged from 1,600 m to 5,000 m with a mean value of 3,525 m. Only one of the four estimates was < 3,000 m. This value suggests *Z. hudsonius* may move > 3 km from their natal site.

My values for this section were higher than most of the experts and my estimate of standard dispersal was the maximum value for the dataset. My values for both standard and maximum dispersal distances matched most closely with those of Expert 2, which is logical given that we both cited the same source (Schorr 2003). Expert 4 also cited the same source, yet provided a smaller value for both distances. Expert 3 cited a slightly older study and again had lower values.

3. *Habitat Patch Size:*

The habitat patch size category asked participants to estimate the minimum area of suitable habitat required to support a single breeding pair of *Z. hudsonius* for one season as well as the minimum areas required to support a small population for 10 breeding seasons. The values provided by the participants are shown in Table 7. Again, one expert declined to complete this section resulting in a total of four different estimates.

Table 7: Estimates of minimum habitat patch size requirements (in hectares) of *Z. hudsonius* for 1 and 10 breeding seasons based on expert opinion (Experts 1-4) via parameter estimation surveys and literature review (Bowe).

	Expert 2	Expert 2	Expert 3	Expert 4	Bowe
1 Breeding Season	N/A	4 ha	1 ha	1 ha	1.5 ha
10 Breeding Seasons	N/A	10 ha	10 ha	100 ha	?

Approximately 1 ha was the habitat patch size for a single breeding season agreed upon by all participants, except Expert 2 who proposed a patch size of 4 ha. The values for habitat patch size over multiple breeding seasons had a ten-fold difference between the maximum and minimum values. This large difference in opinions suggested a very high level of uncertainty. Due to this uncertainty and since this factor was optional in the creation of habitat suitability models, it was not included in the final analysis.

4. *Vegetation Type:*

For the vegetation type, the suitability values were assigned to each of the 33 subcategories by each of the five participants: the four expert opinion and my literature review. The suitability values assigned by each participant are shown in Table 8. The overall results were compared using Spearman's rank correlation coefficient. Simple visual comparisons and analysis were used to compare values within each of the 10 major categories and between the subcategories. Minimum and maximum cost values were also calculated for each subcategory.

In addition, Spearman's rank correlation coefficient was used to provide an overall comparison of the suitability values assigned to this habitat factor by each participant. A matrix of the resulting correlation coefficients is shown in Table 9.

Table 8: Habitat suitability values for the different distance classes vegetation type factor based on expert opinion (Experts 1-4) via parameter estimation surveys and a literature review (Bowe). Values range from 1 – 10 with 1 being highly suitable habitat and 10 being highly unsuitable habitat.

Coniferous Forest (7)	Expert 1	Expert 2	Expert 3	Expert 4	Bowe
Lodgepole Pine	9	7	6	6	5
Ponderosa Pine	9	5	6	7	4
Juniper-Pinion Pine	10	10	7	7	5
Douglas Fir	9	4	6	7	5
Spruce-Fir	9	4	6	8	6
Mixed Pine	9	4	7	7	5
Other Pine	9	9	7	7	5
Deciduous Forest (1)					
Aspen	6	9	4	6	2
Bur Oak	10	7	7	8	4
Deciduous Shrubs (4)					
Gambel Oak Shrubland	10	2	7	7	3
Mountain Mahogany Shrubland	10	7	7	7	3
Chokecherry-Serviceberry-Rose	10	3	7	7	3
Subalpine Shrubland	7	10	7	8	6
Semi-Arid Shrub (2)					
Desert Scrub	10	10	8	8	7
Sagebrush Shrubland and Steppe	10	10	8	7	5
Grassland (6)					
Shortgrass	10	7	4	7	3
Mixedgrass	4	7	4	7	2
Tallgrass	3	7	4	7	3
Introduced Herbaceous Vegetation	6	7	4	8	5
Wet Grassland	2	2	1	6	1
Montane Grassland	5	7	4	8	3
Riparian Vegetation (3)					
Upper Montane Riparian	1	10	1	6	2
Cottonwood-Willow Shrubland	1	2	2	3	1
Floodplain	2	2	3	4	1
Limited Vegetation (3)					
Alpine	10	10	7	9	9
Sparsely Vegetated	10	10	7	9	9
Barren	10	10	9	10	10
Agriculture (1)					
Agriculture	10	5	4	5	5
Developed (3)					
Developed Low Intensity	10	10	5	6	7
Developed Medium Intensity	10	10	6	8	9
Developed High Intensity	10	10	8	9	10
Other (2)					
Open Water	10	10	2	8	8
Snow/Ice	10	10	5	9	10

Table 9: Matrix of Spearman's rank correlation coefficients between the suitability values assigned to the vegetation type factor by each of the five participants.

	Expert 1	Expert 2	Expert 3	Expert 4	Bowe
Expert 1	1.00	0.43	0.47	0.63	0.64
Expert 2	0.43	1.00	0.53	0.34	0.67
Expert 3	0.47	0.53	1.00	0.52	0.74
Expert 4	0.63	0.34	0.52	1.00	0.55
Bowe	0.64	0.67	0.74	0.55	1.00

These results show there was a large amount of variability between the different participant opinions. The strongest correlation was shown between Expert 3's values and my values (Bowe) with a correlation coefficient of 0.74. The weakest correlation was between Expert 2 and Expert 4 with a correlation coefficient of 0.34. The range of correlation coefficients is fairly broad indicating there are noticeable differences between the suitability values selected by the 5 participants.

My values, as derived through the literature review tended to show a high degree of correlation with the expert models than was shown between some of the expert models. The correlation coefficients associated with my values ranged from 0.55 to 0.74 indicating no noticeable difference between the values assigned by the experts and those assigned via literature review.

However, this comparison only applies to the general trends in suitability values assigned by each participant for all vegetation types. The level of agreement or disagreement between the participants also varied at a smaller scale, within each vegetation class and even within vegetation types as discussed below.

For Coniferous Forests, there was variation in opinions among the participants. Expert 1 had cost values of 9 and 10 for all coniferous forest types. Expert 4 assigned all coniferous forest types a cost value of 6 or 7. Expert 3 assigned values of mostly 7 or 8 and I assigned values of mostly 5. Expert 2 was the only one who assigned drastically different values to different categories with values ranging from 4 to 10. The majority opinion rated all coniferous forests types as moderately suitable for *Z. hudsonius* being neither preferred nor avoided.

In the Deciduous Forest category, my values were noticeably less than those of the experts. For aspen, three of the four experts rated this habitat as moderately suitable assigning cost values between 4 and 6. Expert 2 rated this habitat type as strongly avoided with a value of 9. I rated aspen forests as preferred, with a value of 2. A similar trend happened with bur oak where two experts rated the habitat as strongly avoided and 1 rated it as only occasional use. I rated it as suboptimal, but usable with a cost value of 4.

For Deciduous Shrubs, there was even more disparity. Expert 1 ranked all shrubs as strongly avoided except for Subalpine. Expert 3 and Expert 4 assigned cost values of 7 to all categories except for one value of 8. Expert 2 and I both considered Gambel Oak Shrubland and Chokecherry-Serviceberry-Rose to be

preferred habitat. However, I considered Mountain Mahogany preferred habitat

with a value of 3 and Expert 2 rated it as occasional use only (value =7). Expert 2

also considered Subalpine Shrubland as strongly avoided (value = 10), whereas I

considered it occasional use only (value = 6). In this subcategory, my value aligns

more closely with that of Expert 1 and Expert 4 though still slightly low.

All Semi-arid Shrub categories were considered strongly avoided habitat by all

4 experts with the exception of Expert 4 rating Sagebrush Shrubland as occasional

use only (value =7). My values were lower than the expert opinion, but showed a

similar pattern to Expert 4.

For Grasslands, there was a split over the overall suitability of grasslands as a

whole. Expert 2 and Expert 3 rated all grasslands except wet meadows as

occasional use only or avoided. Expert 3 considered Wet Grasslands as occasional

use only (value = 6). The other four participants considered Wet Grasslands

preferred habitat (value = 1 or 2). Expert 1, Expert 4 and myself rated the other

grassland categories as preferred or suboptimal habitat with values ranging from 2

to 5, except Shortgrass which Expert 1 assigned a value of 10. However, despite

the similar range of values, my values tended to be slightly lower than those of the

other two participants.

For the Riparian Vegetation, the results were quite mixed. There was a general

consensus among all five participants that Cottonwood-Willow Shrubland was

highly preferred habitat with values ranging from 1 to 3. Compared to

Cottonwood-Willow Shrubland, Floodplains were considered as equal or only

slightly less preferred habitat by all five participants with values ranging from 1 to 4. Opinions were strongly divided over the suitability of Upper Montane Riparian. Expert 1, Expert 4 and myself ranked this habitat as strongly preferred (value = 1 or 2). Expert 3 considered it occasional use only with a value of 6 and Expert 2 considered the same habitat as strongly avoided (value = 10).

The major category, Limited Vegetation was considered strongly avoided habitat (value = 9 or 10) by four of five participants. Expert 4 rated Alpine and Sparsely Vegetated as "occasional use only" habitat with a cost value of 7 for both.

Agriculture was considered suboptimal habitat by four of the five participants. The exception was Expert 1 who considered agriculture to be strongly avoided, assigning it a value of 10.

The Developed category showed a major difference in opinions. Two experts (Expert 1 and Expert 2) considered all developed lands as strongly avoided. The other three participants all assigned moderate suitability values (5 -7) to the Developed Low Intensity category, strongly avoided values (9 or 10) to the Developed High Intensity category with Developed Medium Intensity rated in between the two.

Open Water and Snow/Ice were considered strongly avoided by 4 of 5 participants. However, Expert 4 considered open water as strongly preferred habitat (value =2) and Snow/Ice as suboptimal habitat (value =5).

5. *Distance from Water:*

   For the distances from water, I was the only participant who adjusted the upper

and lower boundaries, making it difficult to compare my estimates with those of the

four experts. For this reason, the resulting suitability values are split into two

separate tables with my values from the literature review in Table 10 and those of

the four experts in Table 11.   Despite this difference, all participants agreed that

areas within 50 m of a water body was highly suitable with a cost value of 1. There

was also a general consensus that areas > 1,500 m from a water body were

unsuitable habitat with cost values of either 9 or 10. However, in the intermediate

categories there was much more variability. Values for all five assessments ranged

from 1 to 10 in the 50 m – 200 m range and from 5 – 10 in the 200 m – 1,500 m

range.

   Table 10: Habitat suitability values for the different distance classes within
          distance from water factor based on a literature review by the author
          (Bowe.) Values range from 1 – 10 with 1 being highly suitable habitat
          and 10 being highly unsuitable habitat.

Lower Bound (m)	Upper Bound (m)	Bowe
0	50	1
50	200	2
200	600	5
600	1500	8
1500	15000	10

Table 11: Habitat suitability values for the different distance classes within distance from water factor based on expert opinion (Experts 1-4) via parameter estimation surveys. Values range from 1 – 10 with 1 being highly suitable habitat and 10 being highly unsuitable habitat.

Lower Bound (m)	Upper Bound (m)	Expert 1	Expert 2	Expert 3	Expert 4
0	50	1	1	1	1
50	100	7	1	3	4
100	200	10	5	5	5
200	1500	10	10	8	6
1500	15000	10	10	9	9

The cost values assigned for distance from water showed a general agreement that areas < 50m from water were very suitable habitat and those areas > 1,500 m from water were unsuitable habitat. Expert 1 assigned values indicate areas <50m from water were highly suitable, 50-100 were suitable only for occasional use and any farther were strongly avoid. Expert 2 indicated a similar trend with areas < 100m being highly suitable, areas > 200m away being strongly avoided and areas between 100 and 200 m away as usable but suboptimal habitat. This pattern suggests a belief that *Z. hudsonius* are strict riparian obligates. The other three participants (including myself) expressed a more graded opinion with areas close to streams being strongly preferred and suitability gradually decreasing with increasing distance to strongly avoided at distances > 1500 m from a stream. Even then, Expert 3 and Expert 4 both assigned these more distant areas a cost value of 9 meaning they would be strongly avoided, but not completely unsuitable. This value suggests a belief that *Z. hudsonius* have a strong preference for riparian areas, but they are not wholly dependent on the presence of water.

6. *Distance from Roads:*

The values for distance from roads were much harder to compare. All participants agreed close proximity to roads would decrease the suitability of habitat, but the extent of this decreased suitability varied from very strongly avoided (value = 10) to might be occasionally used (value = 6). There was also disparity on the other end of the range with regard to the distance at which roads cease to have an impact. Some experts rated locations > 150 m from a road as perfect habitat (value = 1) while others gave ratings of high, but not perfect suitability (value = 2) even to locations > 16,000 m from a road. The assigned values are shown in Table 12. Note: 16,000 m was used as the upper limited because no location within the area of interest was > 1,600 m from a road.

Table 12: Habitat suitability values for the different distance classes within distance from roads factor based on expert opinion (Experts 1-4) via parameter estimation surveys and a literature review by author (Bowe). Values range from 1 – 10 with 1 being highly suitable habitat and 10 being highly unsuitable habitat.

Lower Bound (m)	Upper Bound (m)	Expert 1	Expert 2	Expert 3	Expert 4	Bowe
0	50	10	10	6	9	9
50	100	5	7	4	4	5
100	150	5	5	4	4	5
150	200	1	1	4	4	5
200	15000	1	1	2	3	1
15000	20000	1	1	2	2	1

All five participants assigned the highest values to the areas closest to roads indicating they expected to see some road-edge effect or road avoidance exhibited by *Z. hudsonius*. However, there was a difference of opinions as to how strong this

effect would be. Two participants said the presence of road would make the area almost completely unsuitable for *Z. hudsonius*; they gave a cost value of 10. Two participants, myself included, gave a cost value of 9, indicating roads would be strongly, but not completely avoided. Personally, I based this cost value on the fact *Z. hudsonius* have been observed to cross roads, indicating there is at least some use of this habitat. One participant, Expert 3, assigned the areas immediately adjacent to roads a value of 6 stating he had previously captured *Z. hudsonius* in such areas. However, he also stated "… since vegetation and water quality near roads can sometimes be poor, habitat farther from roads is probably preferable." Two participants also assigned cost values of 1 to all distances > 150 m indicating a belief that the impact of roads was limited to close proximity to the road. On the other end of the scale, two participants assigned a cost value of 2 to areas > 15,000 m. This designation was rather puzzling as it suggests the presence of roads still has a slight impact on habitat suitability even at a distance of 15 km. It is possible there was some misunderstanding that these values apply only to impact of roads on habitat suitability and not to the general suitability of areas of high road density indicating higher levels of human activity.

Concerning the impact of roads, my assessment matches fairly closely with the experts' assessments. The major difference was I assigned slightly higher cost values to the areas between 50 -200 m from the road than did most of the experts. This could be because I was also considering roads as a proxy for human activities and disturbance. I was considering this more abstract interpretation when I initially selected this factor, but this abstraction was not stated in the surveys when they

were sent to the other participants. Therefore, it is doubtful this interpretation is
included in the suitability rankings of the other four participants.

It is also important to note that while Expert 1 and Expert 2 both provided cost
values for distance from roads, they gave this factor a weight of 0 in the overall
factor weights. This meant distance from roads was not included in the habitat
suitability models generated for these two participants.

D. Comparing Different Factor Weights:

The first set of models run compared the effects of different factor weights with the
suitability values held as constant. My suitability values were used for all five models, but
each model had a different combination of factor weights as outlined in Table 13.

Table 13:   Weights based on relative importance of each factor on determine
            habitat suitability for *Z. hudsonius* as assigned by the author. These were
            used to develop five habitat suitability models which were compared to
            determine the impact of weights on the overall model. Factor weights
            were required to sum to 100. (Copy of Table 5)

	Bowe A	Bowe B	Bowe C	Bowe D	Bowe E
Vegetation Type	55	60	45	50	65
Distance from Water	40	30	45	50	35
Distance from Roads	5	10	10	0	0

The values were chosen to access the sensitivity of the model to:

- Inclusion or exclusion of the distance from roads factor (C vs. D) and (B vs. E)

- Small changes in the weights of each factor (A vs. B)

- Similar or different values for vegetation type and distance from water (B vs. C)

Figure 3: Five habitat suitability models generated using the suitability values derived from a literature review for each of the three habitat factors: vegetation type, distance from water and distance from roads. The models differ in the weight assigned to each factor in the analysis. Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range of *Z. h. preblei*.

1. General Comparison:

The five models (Figure 3)[2] display very similar overall trends. The areas of

high suitability (shown in green) tend to be clustered around rivers. There is an

extensive suitable patch near the South Dakota/Nebraska border in the Oglala

National Grasslands. This extends northwards along the Cheyenne River and into

Black Hills National Forest. There is a very noticeable patch of unsuitable habitat

near the town of Lusk, Wyoming where Highway 20 and Highway 85 intersect. A

slightly patchier area of unsuitable habitat is found northwest of Lusk, in the area of

Douglas and the Thunder Basin National Grassland. Other areas of unsuitable

habitats are also found near Rapid City, SD (upper right), Torrington, WY (lower

center) and Gillette, WY (upper left).

Two noticeable errors are also apparent in all of the models. In the lower right

quadrant of all models, there is a white area where no data is present. This was

identified as a small region for which distance from water exceeded 15,000 m.

Since the suitability values assigned for distance from water did not include a

category for distances > 15,000 m there was no value assigned to these cells in the

reclassification. As a result, the software was unable to compute an overall

suitability score for these cells and kept them blank as "no data." This was

corrected in Model B for the later assessments.   Additionally, there are three

irregular patches appearing in the upper left of each model that are classified as

highly suitable. These irregular areas had a much higher density of streams than the

surrounding regions due to a flaw in the hydrography dataset. This flaw is

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[2] Larger versions of all models are available in Appendix D.

discussed in more detail in the errors section of the discussion on page 61. This error could not be corrected.

Examining these models more closely, patterns between them become apparent. Model B appears most similar to Model E and Model C closely resembles Model D. Model A does not fit neatly with either of these pairings, but appears more similar to Models B and E than to Models C and D.

2. *Inclusion or Exclusion of the Roads Factor*

The similarities between Models B and E and also Models C and D, is not surprising given that relative proportions between the two main factors, vegetation type and distance from water are kept similar between Model B and Model E with the major difference being the inclusion of the roads factor in Model B. The same pattern occurs with Models C and D; the relative proportions of vegetation type and distance from water are constant, but Model C includes distance from roads and Model D does not.

Comparing these models visually, the two models which contain the roads factor show slightly less red, indicating a slightly higher suitability, at least in some areas. With the inclusion of this factor, we would expect to see decreased suitability in the areas close to roads. However, any area > 200 m from a road was considered preferred habitat, increasing the overall suitability of these areas slightly. In addition, the proportion of factor weights assigned to distance from roads means that less emphasis is placed on the vegetation type and distance from

water. This reduction could also result in an increase in overall suitability as it reduces the impact of vegetation or hydrological characteristics.

Interestingly, the same pattern around the towns is exhibited in both models irrespective of the inclusion of distance from roads. These areas likely retain their unsuitable classification based on the vegetation type factor that also included categories for more general landcover types including developed areas. In the area near Lusk, WY, the vegetation type grid also shows high amounts of introduced vegetation in the area, which would also have lower suitability. It is also possible the effects of roads and human disturbances are encompassed by the vegetation type factor, which includes categories for developed areas. Specifically, roads were included in the Developed Low intensity category so there is overlap between these factors.

3. *Effects of Changing All 3 Factors*

Comparing Models A and B provided a sense of how changing all three factors slightly could change the overall outcome. Model A appears to have a slightly larger proportion of unsuitable areas. Model A also tends slightly more towards the extremes with fewer of the intermediate suitability areas seen in Model B. Again, these trends suggest the increased weight of the roads factor may be serving to partially counter-balance the negative effects of the other two layers. This balancing could been as either a positive or negative effect. It is positive because it allows us uncover more subtle trends in the mid-ranges. However, it is also a

negative effect because it could be creating a more overly optimistic perspective on suitability/ overriding the effects of the more important factors.

4. *Altering the ratio between factors*

Model B and Model C were compared to assess the effects of altering the ratio between the two most important factors (vegetation type and distance from water) on the outcome. In both models, distance from roads was held constant with a factor weight of 10. However, in Model B vegetation type is given twice the weight of distance from water, while in Model C, both are weighted equally

Comparing the two, Model C shows a higher proportion of unsuitable areas, especially in the western areas. It also tends toward the extremes, showing fewer areas of moderate suitability and less of the subtle variation between areas.

The increase in the proportion of unsuitable areas suggests an increased emphasis on close proximity to water can restrict suitability to only riparian areas. The reduction in subtle variation in the moderate suitability regions is likely due to the increased emphasis on the distance from water factor. Distance from water varies in a more continuous manner, whereas vegetation type has more random variations. Increasing the emphasis on distance from water would reduce the random variability seen in the model because this factor exhibits variation in a more continuous manner and would serve to smooth out the variations in the overall habitat suitability model. This trend is even more apparent when comparing my results to those of the other participants, all of whom weighted distance from water as the most important factor.

5. *Selecting a Representative Model*

Overall, Model B was selected to be the representative of the set of models generated using the literature-based suitability values. This model was used when comparing my modeling results to those of the other four participants. It was chosen because it includes all three factors, each of which I feel contributes to the suitability of habitat for *Z. hudsonius*. It also has vegetation type weighted as significantly more important than distance from water, which was an opinion that differed between myself and the experts surveyed. All four of the experts surveyed ranked distance from water as the most important habitat factor with vegetation type being secondary. I felt the preference for close proximity to water exhibited by *Z. hudsonius* is more tied to the composition of the vegetation found near water than to the actual physical presence of water. Therefore, I felt the vegetation type factor partially encompassed this preference for riparian areas, making the actual physical distance from water of secondary importance. I was interested in comparing my modeling strategy to those of the surveyed experts in this regard and selected the model which I felt best represented this distinction: Model B (shown in Figure 4).
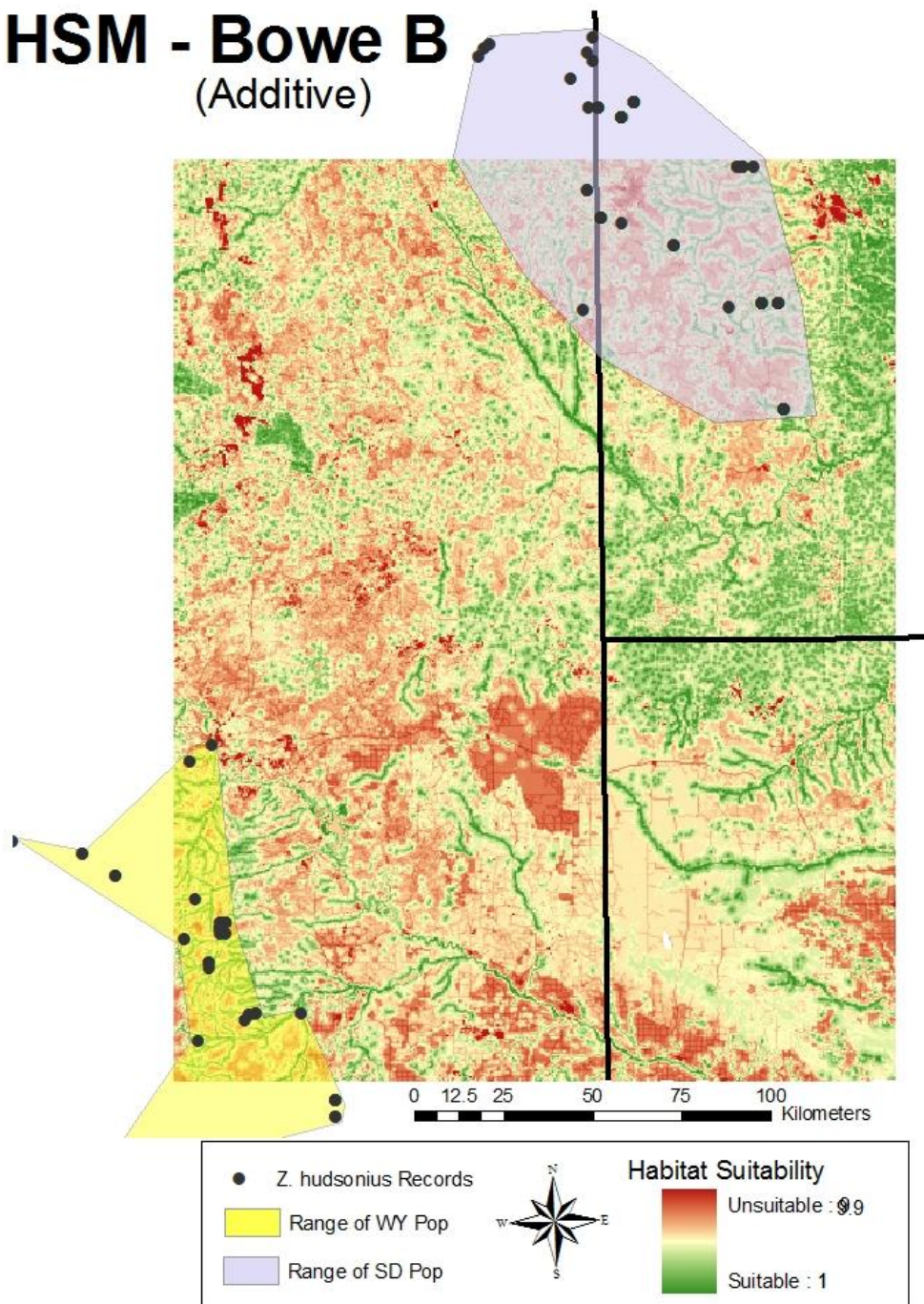
Figure 4: A larger copy of Model B, the model selected to represent my suitability values in the overall analysis. Model B uses suitability values derived from a literature review by the author and factor weights of vegetation type (60), distance from water (30) and distance from roads (10).

E. Comparing All Participants:

Next, Model B, representing my view was compared to the models generated based on the results of each expert survey. This included both the suitability values provided for each factor and the relative weight of each factor. This resulted in a total five models shown in Figure 5.

Two of these models immediately stand out as drastically different from the other three: Expert 2 and Expert 1. These other three, the two other expert model and my own, all show the same general trend, but with different degrees of suitability.

Expert 2 shows the majority of the area of interest as unsuitable except for the areas immediately adjacent to water bodies. This pattern likely results from a combination of the suitability values assigned to distance from water and the weight of this factor. The suitability values Expert 2 assigned to the distance from water categories suggest *Z. hudsonius* is a strong riparian obligate with any habitat > 200 m from a water body being strongly avoided. This pattern was amplified in the model because distance from water was ranked as the most important factor with a weight of 70 leaving vegetation type with a weight of 30 with regard to habitat suitability. The other interesting trend occurring in this model is extremely high levels of unsuitability in the northwest corner of the analysis area. This trend was even more apparent when a second model was generated using Expert 2's suitability values, but with vegetation type weighted higher (75:25). This increase suggests this trend is the result of unsuitable vegetation types in the region more than a lack of water. The vegetation type most prevalent in this area is Sagebrush Steppe which Expert 2 ranked as highly unsuitable (value = 10).

Expert 1's model shows few of the common trends seen in the other models. The area around the White River in Nebraska was classified as mostly suitable in the other models, yet appears as mostly unsuitable in Expert 1's. Conversely, some of the areas seen as unsuitable in the other models, such as Thunder Basin National Grassland are classified as largely suitable in this model. In Expert 1's model two of the most extensive areas of unsuitable habitat are the areas designated as the current ranges of both subspecies. The locations containing known *Z. hudsonius* sightings and captures are classified as only moderately suitable. This disparity suggests the model parameters are not encompassing the actual habitat preferences of *Z. hudsonius*.

Both of these models were eliminated from further analysis due to these major differences. Expert 2 showed the vast majority of the landscape as unsuitable habitat. While this perspective may be correct, especially if *Z. hudsonius* are indeed strong riparian obligates, it did not support the primary goal of this study, which was to isolate areas of potentially suitable habitat which should be explored for the presence of *Z. hudsonius*.

Since this model showed very little potentially suitable habitat, it was deemed there was nothing to be gained by further analysis. The model generated from the responses of Expert 1 showed patterns which were often contradictory to those seen in the other four models. In particular, the areas representing the known ranges of *Z. hudsonius* were determined by this model to be mostly unsuitable. For this reason, it was deemed best to eliminate this model and continue analysis with the three models which exhibited similar suitability trends.

Figure 5: The four HSMs created using suitability values and factor weights assigned by each expert via parameter evaluation surveys. (4A, B, C and D). And HSM generated using the suitability values derived from a literature review (4 C). Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range of *Z. h. preblei*.

These three models all agreed on the same general trends with major differences in the extent of the variability. All three showed to some extent the basic pattern described in my models with extensive areas of suitable habitat in Oglala National Grassland and along the

major river systems and unsuitable habitat near the towns of Lusk, Rapid City, Gillette and

Douglas as well as in the Thunder River Basin. Expert 4's model visually had the most

polarity with very few areas of moderate suitability. There are large areas considered

suitable (green) and large areas considered unsuitable (red) with very abrupt transitions

between areas of high and low suitability. Expert 3 showed similar distinct areas of high

and low suitability, but with more gradual transitions between them with areas of moderate

suitability in between. This difference is likely due to the fact Expert 3 assigned more

balanced weights to the distance from water and vegetation type factors with a 55:45 ratio,

whereas Expert 4 assigned weights of 60 and 30 respectively. Compared to the other two

models, my model shows significantly more noise with small patches of suitable,

unsuitable and moderately suitable habitat all intermixed. However, the same larger trends

are still apparent with closer inspection. The increased variation in my model is most

likely due to the fact I was the only one of the four participants who weighted vegetation

type as more important than distance from water. While distance from water varies along a

fairly smooth continuum, vegetation by nature is much patchier and distinctly different

vegetation types can often be found in close proximity. This effect is even more

pronounced when the vegetation is aggregated into discrete categories by dominant

vegetation type as was done in this dataset. This aggregation tends to mask some of the

naturally occurring transitions between different vegetations communities.

These three models were also compared statistically to determine the percentage of grid

cells having the same suitability classification in each set of models. These statistics were

based on the four suitability categories outlined in the Materials and Methods (Table 7,

page 39) and calculated using ArcMap. The results are shown in Table 14.

Table 14: Statistical comparison of the top three habitat suitability models, showing proportion of cells classified the same in both models, classified differently or classified drastically differently (difference between categories > 2). The suitability values were classified on a scale of 1 - 4 with 1 being highly suitable and 4 being highly unsuitable.

	Same	Different	Drastically Different
Bowe B vs. Expert 4	40.6	59.4	1.2
Bowe B vs. Expert 3	18.1	81.9	5.7
Expert 3 vs. Expert 4	52.8	47.2	-

This analysis reveals that while Model B and Expert 3 visually appear more similar they are in fact over 80% different. The two expert models showed the most similarity, but even these had just over 50% similarity. This large difference further emphasizes the high variability between the expert opinions regarding habitat suitability factors. These two models were the most similar of the original five, and yet are only 52% similar. This high level of disparity serves to further emphasize the lack of agreement, even among experts, as to what factors comprise suitable habitat for *Z. hudsonius*.

When all three models were compared simultaneously, only about 5% of the area was assigned a different overall suitability value in each of the three models (Figure 6). 85% of the area had two of the three suitability values the same and 9.4% of the area had the same suitability value in all three models. Of this 9.4% with the same suitability, about half was classified as either suitable or moderately suitable (Figure 7). This comprised a total of 2% of the analysis area or about 1,000 km^2.

Unsuitable Areas

Figure 6: Portions of the analysis area classified as highly unsuitable on all three HSMs or moderately unsuitable on all three HSMs (in black). Portions of the analysis area classified as highly suitable on 2 of 3 HSMs or moderately unsuitable on 2 of 3 HSMs (in red). Known population ranges of Z. hudsonius in southeast WY and western SD are outlined in black.

Suitable Areas
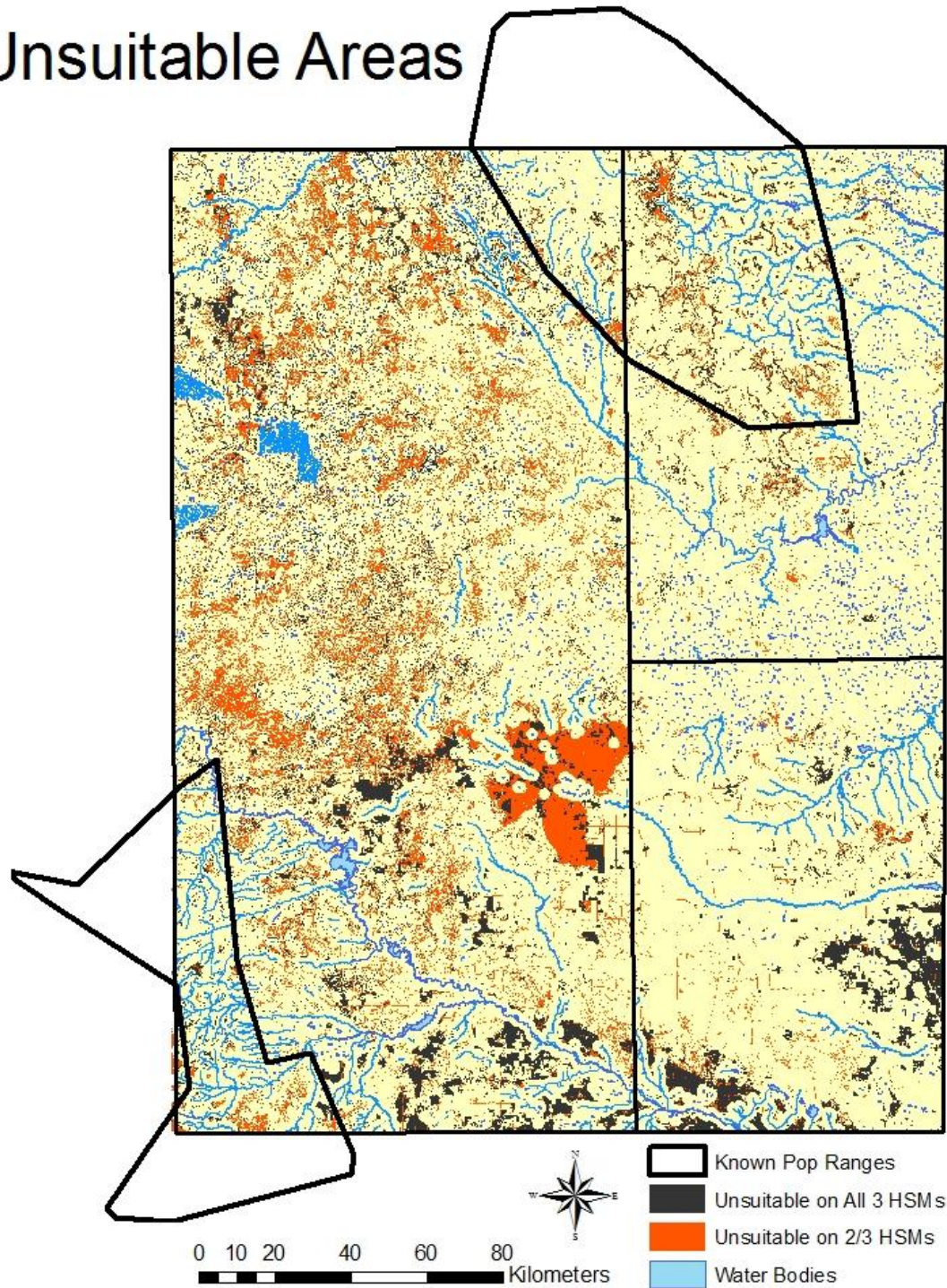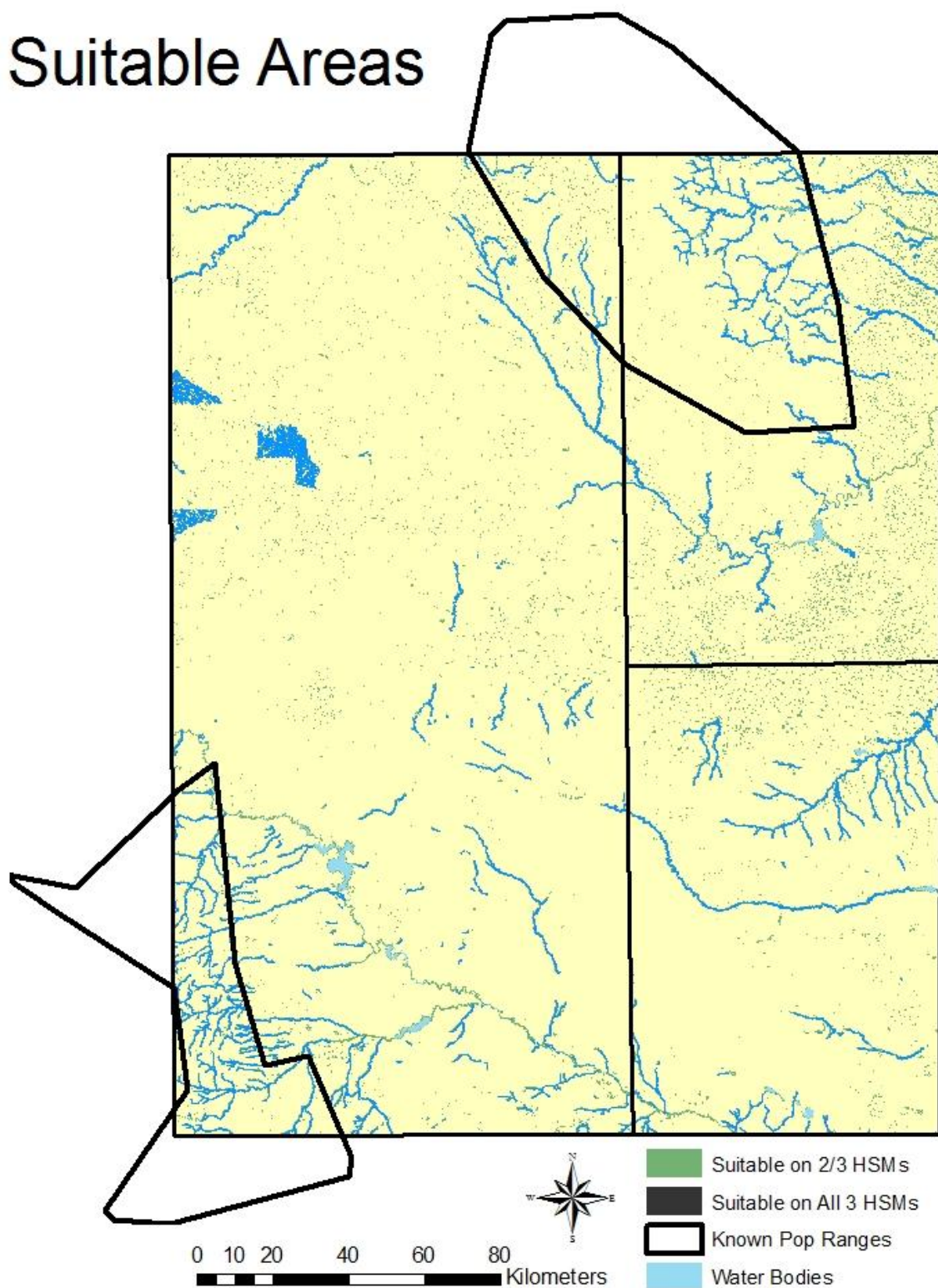

Figure 7: Portions of the analysis area classified as highly suitable on all three HSMs or moderately suitable on all three HSMs (in black). Portions of the analysis area classified as highly suitable on 2 of 3 HSMs or moderately suitable on 2 of 3 HSMs (in green). Known population ranges of Z. hudsonius in southeast WY and western SD are outlined in black.

Visually examining the results of the overlay, it is evident the majority of areas classified as suitable by at least two of the three participants are on or immediately adjacent to water bodies. This is logical as distance from water was weighted as the most important factor by two of the three participants with a weight > 50. However, this means the amount of suitable habitat is overestimated since the model considered areas on open water as suitable habitat because it has a distance from water of 0. Realistically, *Z. hudsonius* will not inhabit open water and the more expansive streams and rivers could actually serve as a barrier to individual dispersal. The overlay of unsuitable habitat shows that a large portion of the northwestern portion of the analysis area is considered unsuitable habitat by at least two of the three participants. This portion includes the Thunder Basin National Grassland. The patchiness observed suggests this pattern might be the result of vegetation type. The area is mostly a mix of grassland, agriculture and semi-arid shrubs with interspersed regions of limited vegetation. Grasslands were considered moderately suitable in two of the three models and agriculture was considered moderately suitable in all three models. Semi-arid shrubs were considered moderately unsuitable in two of the three models and limited vegetation was highly unsuitable in all. These patterns of suitability values are likely reflected in the visual patterns shown on the overlay. The unsuitable patch south of Gillette, WY was considered unsuitable in all three models and the area around Lusk, WY appeared as unsuitable in at least two of three models, with sections that were considered unsuitable by all three models. Several smaller patches appear in the bottom center, which were not apparent in the individual models. These areas appear to be associated with agricultural land use.

F. Areas of Interest

Two smaller areas within the analysis area consistently appeared on all three models and are therefore relevant to the secondary purpose of the present study which was identify key areas to survey for the possible presence of intermediate populations of *Z. hudsonius.* The first is the area near southeast of Douglas (labeled as A in Figure 8). This area is positioned in line between the known populations of *Z. hudsonius* in Wyoming and appeared as highly suitable in the three top models. The area contains two major water features, the Glendo and Guernsey reservoirs, both of which are surrounded by a state park. The second area of interest is near area surrounding the town of Lance Creek, WY (labeled as B in Figure 8). This area is present as a patchy mix of suitable and moderately suitable habitat on all three models to varying degrees. Another area, just south of Gillette, WY appeared as unsuitable on all models (labeled as C in Figure 8). Satellite photos revealed the area as highly disturbed by what appeared to be a resource extraction operation, likely natural gas wells.

Areas of Interest
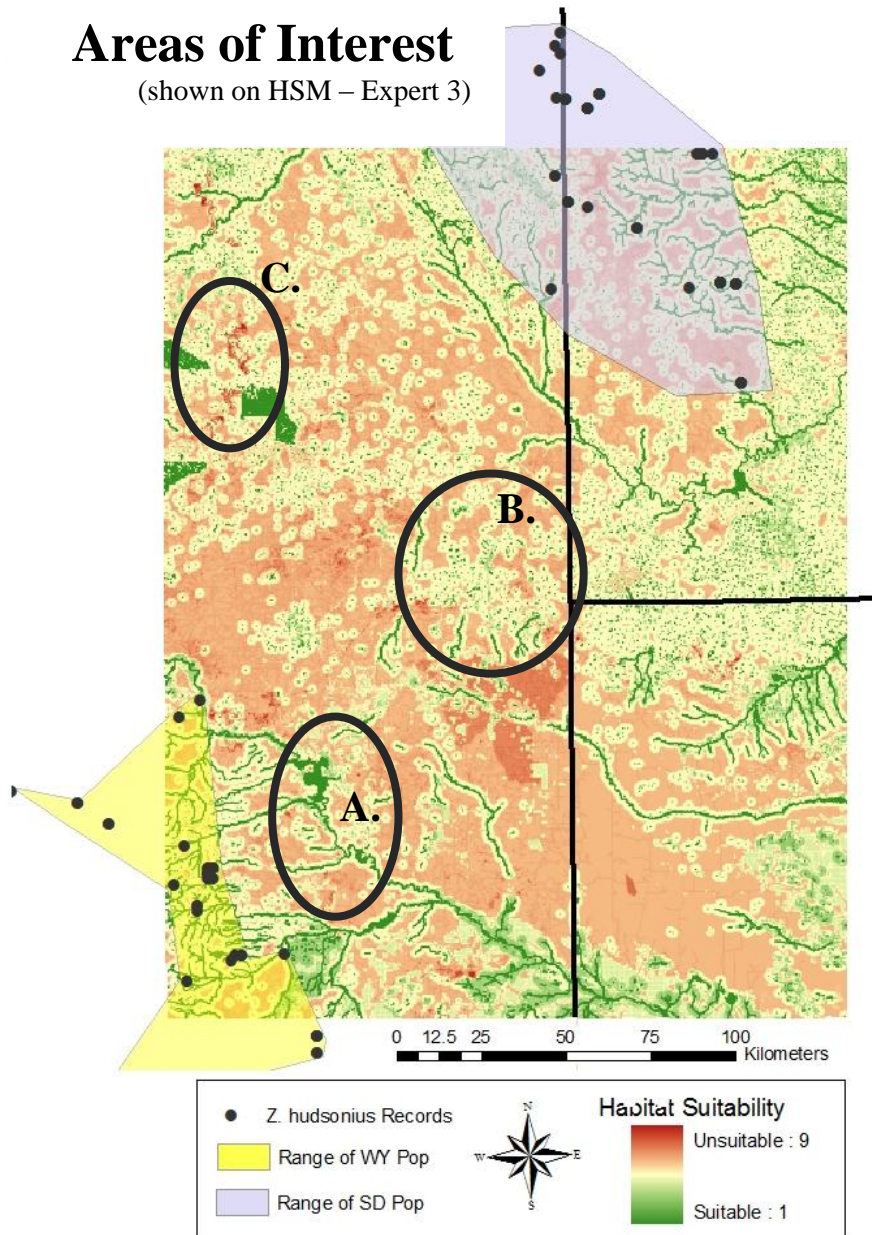
(shown on HSM – Expert 3)

Figure 8: The five habitat suitability models generated using the suitability values and factor weights of each participant, the four experts and myself. Model B was chosen to represent my suitability values.

V. DISCUSSION:

A. Summary of Results

The present study had two primary objectives. The first objective was to determine if there was potentially suitable habitat for *Z. hudsonius* in the area between the Wyoming population of *Z. h. preblei* and the South Dakota population of *Z. h. campestris.* The second objective was to identify smaller areas which could be examined for the existence of potential subpopulations of *Z. hudsonius* to determine if these potentially suitable habitats are actually occupied. Both objectives were successfully accomplished in this study.

For the first objective, five habitat suitability models were generated: four based on expert opinions and one based on a literature review. Of these five, one model was eliminated because the resulting suitability predictions conflicted with known locations of *Z. hudsonius*, suggesting a discrepancy between the suitability model and the actual preferences of the *Z. hudsonius*. One model showed almost no suitable habitat throughout the study area due to the dominance of close proximity to water as an explanatory factor, thus matching with the view of *Z. hudsonius* as a strong riparian obligate. The other three models all showed small patches of suitable habitat scattered throughout the analysis area. Two of the three models had over 30 % of the analysis area classified as suitable or moderately suitable for jumping mice. In addition, 2% of the analysis area or about 1,000 km^2 appeared as highly suitable on all three models or moderately suitable on all three models supporting the conclusion that there could be patches of suitable habitat for *Z. hudsonius* outside of the known population ranges.   It is possible *Z. hudsonius* are indeed

strong riparian obligates as Expert 2 suggests, which would mean there is very little

suitable habitat available in the analysis area. However, the presence of suitable habitat in

the other three models indicates it would be worth further investigation to determine if

patches of suitable habitat and possibly populations of *Z. hudsonius* are present in this area.

Providing focused locations for population studies was the second objective of this

study. To this end, the three models displaying higher levels of suitable habitat were

analyzed further. These small areas, termed areas of interest, were selected based on the

presence of suitable habitat across all three models, the capability of the area of contiguous

habitat to support multiple breeding pairs and the position of the area directly between the

two known populations. Based on these criteria, two areas were selected, one at the

Glendo and Guernsey reservoirs (Figure 9 A) and one in the area surrounding Lusk, WY

(Figure 9 B). These areas are the recommended targets for future research. If intermediate

populations of *Z. hudsonius* are present in the analysis area, they will likely be found in at

least one of these two areas. The existence of such populations could have important

implications for the conservation and management of *Z. hudsonius* in the western Great

Plains as will be discussed later.

Figure 9: Close-up of the area surrounding the Glendo and Guernsey reservoirs (A), and near Lusk, WY (B). These are the two recommended sites for future trapping studies of *Z. hudsonius.* Portions of the analysis area classified as highly suitable on all three HSMs or moderately suitable on all three HSMs are shown in black. Portions of the analysis area classified as highly suitable on 2 of 3 HSMs or moderately suitable on 2 of 3 HSMs are shown in green.

B. Limitations of the Models:

The habitat suitability maps and movement corridors included here are models, and like all models they have certain inherent weaknesses. These limitations must be considered when using these models as predictors of habitat suitability. Most prominent among these limitations are the limited availability of data, the subjective nature of the suitability values and positional errors.

1. Data Availability

The most significant limitation of the models was the availability of both spatial data and population data.

    i. Spatial Data

Z. hudsonius is a known riparian corridor dweller, so high quality hydrographic information was required. Multiple datasets were considered, but rejected because they did not discriminate between intermittent and perennial water bodies. The National Hydrography Dataset was finally selected because it included lakes, ponds, swamps and other water bodies in addition to streams and had different categories for permanent, ephemeral and intermittent water bodies. The other benefit of NHD was its consistency in all states, thus avoiding the problems of combining disjointed statewide datasets. However, multiple inconsistencies in the classification of water bodies were noted. Certain features such as swamps lacked the finer distinctions and were all classified simply as swamps. For other features four distinct classifications were present: unclassified, perennial, ephemeral and intermittent.

The most obvious problem with hydrography is the three anomalous areas in the upper left of the analysis area that contain an abnormally high stream density (Figure 10). The angular shape of these areas suggests they are a man-made artifact in the data associated with township boundaries. In this case, the streams were likely not separated into intermittent, ephemeral and permanent categories and instead classified simply as streams. To avoid having large gaps in the coverage, streams in the first two categories (Streams (unclassified) and

Permanent Streams) were both included when extracting water features. As a result, all of these streams appeared in the analysis despite the fact some of these streams may be dry most of the year. Some of the other streams under the more general designation (Streams) are likely intermittent or ephemeral as well, but these could not easily be distinguished given the available data.

Figure 10: Close-up of the region in the upper left of the analysis area, showing anomalies in the hydrography data attributed to over-generalization of stream data.

The other noticeable issue with the hydrography data is the presence of small stream and river segments disconnected from the rest of the stream network. These segments could easily be the result of an error in the dataset, which is not an uncommon issue with hydrography data. However, given the natural hydrography of the area in question is it also possible these segments

are the result of streams which are permanent in some areas and intermittent or ephemeral in others or streams which flow partially above and partially below ground. Ground truthing or overlay with satellite imagery would be necessary to determine the actually status of these streams.

ii. Availability of *Z. hudsonius* records

As mentioned in the results for *Z. hudsonius* records, there was a noticeable lack of current location data for *Z. hudsonius*. Less than 50% of the *Z. h. preblei* records obtained and used in this study were from within the last decade. This age bias in the records was even more apparent with regard to *Z. h. campestris*, where > 80% of the records used were older than 1970. Unfortunately, this lack of current information means some of the locations used to represent the population range of each subspecies in this study may not have supported *Z. hudsonius* populations for decades.

2. *Suitability Values*

As can be seen from the literature review the habitat requirements of *Z. hudsonius* are not clearly understood and in some cases there was noticeable disagreement between different studies and researchers. For factors such as distance from roads, there were no studies concerning the road edge effect in *Z. hudsonius* and the impacts of this factor had to be extrapolated from studies of other species. In addition, no data was available which directly quantified or ranked the suitability of the categories for each factor used in this study. Expert parameter surveys were included to increase the credibility and hopefully the validity of the

results. However, even among the experts there were some distinct differences in opinion regarding the effect of each habitat feature.

In addition, other factors which could potentially have a strong impact on habitat suitability had to be excluded from this analysis because there was a lack of information on how these factors impact suitability. Most prominent among these was the elevation factor which was eliminated from the present study because the information available did not significantly differentiate habitat in the analysis area.

For other habitat factors, the available information on suitability was so sparse that information from other subspecies and even species had to be used with the assumption that *Z. hudsonius* would exhibit similar preferences. The primary example of this issue was the distance from roads factor where information from studies of *Peromyscus spp.* had to be used because there was no available information on how *Z. hudsonius* respond to the presence of roads. While necessary, such assumptions could have a significant impact on the results and must be considered when interpreting the results.

3. Positional Accuracy and Spatial Scale

The accuracy of the positional data for *Z. hudsonius* records ranged from 10 m to > 8 km. While this did not directly impact the resulting models, it did make it difficult to gauge the success of the models. In theory, the models should have assigned a suitable rating to areas with known *Z. hudsonius* captures and this fact could be used as a rough estimate of the success of the models. In reality, the low

positional accuracy of these data points made such a comparison too unreliable to be of any use.

When working with spatial data, there is an inherent trade-off between the quantity and the quality of datasets; a finer resolution dataset will include finer distinctions between areas, but will also drastically increase the file size and processing time. Due to the large size of the analysis area, a 30 m x 30 m resolution was chosen, because this was the resolution of the LANDFIRE datasets. This resolution allowed detail to be displayed a relatively fine scale without the size of the dataset becoming unmanageable. However, when working with an organism the size of a mouse, there is a large amount of variation in microhabitat use, especially regarding the vegetation types, which is not encompassed by 30 m x 30 m cell aggregates. Again, this restriction was necessary due to the nature of the dataset used, but this limitation should be considered when interpreting the results.

C. Future Directions for Research:

1. Ground Truthing

These models represent the best approximation of habitat suitability based on the data available for this study. However, significant ground truthing will be necessary to further assess the validity of these models. Areas identified as potentially suitable habitat should be physically examined to determine vegetation community matches with the known habitat preference for *Z. hudsonius*. It would also be important to determine if the water sources upon which these models were based are both present and permanently available. The potentially suitable areas should also be explored for the presence of other factors, possibly influencing the

suitability of habitat, which were not encompassed by the parameters used in the creation of these models. Such factors include the amount of vegetative cover in the area, a factor known to be an important component of *Z. hudsonius* habitat which unfortunately could not be included in the models. Such ground truthing could be used to determine if the models did indeed identify habitat which could potentially support populations of *Z. hudsonius*.

Ultimately, however, the presence of suitable habitat is largely irrelevant if this habitat is not occupied by *Z. hudsonius*. For this reason, it would also be necessary to trap within these potentially suitable habitats for the presence of *Z. hudsonius*. Because of the limited availability of funds and personnel to conduct necessary to conduct thorough trapping studies, a small scale trapping study of a few key areas would be much more feasible than a large scale study of the entire analysis area.   I would recommend trapping studies of *Z. hudsonius* be focused on the two areas identified by this model as having the most potential for success. These would be the areas of interest identified in Figure 5, which showed high levels of suitability across multiple models: the Glendo and Guernsey Reservoirs and the area surrounding Lance Creek, WY. For the Glendo and Guernsey Resevoirs some of the high levels of suitability appearing visually are due to the presence of a large body of water which was considered highly suitable according to the distance from water factor. The analysis did not account for the fact *Z. hudsonius* cannot live directly on an open body of water. Nevertheless, this area is also well-connected to many other areas of potentially suitable habitat through a network of attached streams. I would recommend that studies in the state parks should be focused along

these connected streams. The area near Lance Creek, WY is patchier in suitability and may be more difficult to survey effectively. I would recommend that studies in this areas focus on identifying some of the numerous water sources shown to exist in the area. If the existence of at any of these water bodies is confirmed, then trapping could be conducted in the area adjacent.

On a cautionary note, it should be noted that these areas may fall on private property. Due to the controversial issues surrounding this species and the potential for it to be relisted as a threatened species, landowners may not wish to have their land surveyed, especially by the government. This resistance would not be an issue on the state parks which are already government owned and run by WY State Parks and Cultural Resources.

If *Z. hudsonius* are found at either of these two locations, it could indicate the presence of multiple subpopulations existing in this intervening region and trapping efforts can be expanded to other parts of the region. If no *Z. hudsonius* are found in either of these areas, it would mean either the models are not highly accurate and the habitat is not suitable, or the habitat is suitable, but individuals are not able to reach these habitat patches. If the former is true, then the models should be reevaluated to determine which habitat factors are missing or misrepresented. If the latter is true, than the landscape should be explored for the presence of barriers which could limit the ability of *Z. hudsonius* to disperse to these habitat patches.

2. Filling Gaps in the Data

Landscape level spatial data is by its very nature subject to inaccuracies. Most of this data is derived from remotely sensed information and errors in processing this information are not uncommon. In addition, the long processing time between initial data collection and the production of the final datasets means by the time a dataset is published, some portion of it is likely outdated. This is especially true when modeling dynamic variables such as land cover type. Most of the spatial data used in this study was updated within the past few years, so the currentness of the data was of only minimal concern.

Much more concerning was the very limited location data available for *Z. hudsonius*. Only about 45 % of the available records of *Z. h. preblei* sightings and captures were within the last decade. With *Z. h. campestris*, the situation is even worse. Only 16% of the *Z. h. campestris* records were from studies after 1968. The older records were more numerous, but most of them were part of general small mammal trapping studies conducted by the University of Kansas between 1961 and 1968 (Rinker pers. comm.). To date, no specific studies targeted at *Z. h. campestris* have been conducted in South Dakota. In Wyoming, *Z. h. campestris* have been observed in the Belle Fourche River basin, but no surveys have been conducted for its presence in other areas. This lack of data means there is currently no solid estimate of population size or population trends. However, the subspecies *Z. h. campestris* is currently considered by WYNDD to be of moderate conservation concern (Beauvais, 2000). There is also very little information available on the habitat preferences, movement and life history of this subspecies. Most of the

information on these topics used in this study was based on studies of *Z. h. preblei* or *Z. h. intermedius* and *Z. h. luteus* with the assumption that *Z. h. campestris* would show similar trends. However, this assumption has not been well tested. Specific studies targeted at accessing the ecology and population status of this subspecies should be conducted to fill this information void.

D. Future of Meadow Jumping Mice

The future of *Z. hudsonius* in this region revolve around two main issues: its taxonomic status and its conservation status. The taxonomic status, whether *Z. h. preblei* is a unique subspecies or merely a population of the subspecies *Z. h. campestris*, has not been satisfactorily resolved. In this study, a different approach was suggested: examining the potential for gene flow between the two known populations in the area rather than focusing on the existing genetic variation in each. If smaller subpopulations can be found in the intervening region, it suggests genetic information might be moving between populations. If the two populations shared a common gene pool, then they would not be considered on separate evolutionary trajectories.

The problems concerning the conservation status of *Z. hudsonius* are primarily socio-political issues associated with living with a federally endangered species. The restrictions on land use, development and agriculture enacted to protect the population sparked a larger amount of conflict and controversy in Wyoming and Colorado. In Wyoming, these issues were alleviated with the official delisting of *Z. h. preblei* from the ESA in 2008. However, recent Supreme Court proceedings regarding the ESA and the listing or delisting of species have created a very real possibility *Z. h. preblei* could be relisted in the near future. If this happens, the old issues and conflicts would flare up again.

The concern over its conservation status would lessen if *Z. h. preblei* was indeed found to be a subpopulation of *Z. h. campestris*. This would mean the small population currently consider as threatened at a federal level would only represent a portion of a larger population. That being said, the size of the population of *Z. h. campestris* in the region and the current population trends of this species are unknown. It is highly possible this subspecies is also suffering from increased human activity and habitat loss. In addition, the fact that the population currently considered *Z .h. preblei* is threatened by habitat loss and increase human activity would not change with its taxonomic status. Even if *Z. h. preblei* were not relisted federally, state agencies should continue to monitor *Z. h. preblei* populations as a species of concern.

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APPENDIX A:

Parameter Estimation Survey that was sent to various experts in *Z. hudsonius* ecology soliciting their input for this project. The copy below was completed by the author and represents the suitability values used to create the models termed Bowe A – E.

INSTRUCTIONS

Your Name:	Amanda Bowe
Your Email:	

If you have any questions, please contact us:

Amanda Bowe	alb5249@psu.edu	484-256-8189
Jacqualine Grant	jbg13@psu.edu	814-863-0135

I am requesting your help with my senior thesis. In particular, I need your expertise to help parameterize a GIS model. I am attempting to use least cost analysis to model habitat suitability and identify potentially suitable habitat patches for Meadow Jumping mice (Zapus hudsonius) in the region between the Laramie Mountains in Wyoming and the Black Hills of South Dakota.

I assure you that your input, transformed via the pseudo-precision of GIS analysis, will not be the only analysis. I plan to use the resulting permeability maps to suggest key areas for future field studies to further our understanding of the distribution and status of Zapus in the region.

Terminology. We are building permeability models that use four factors, each of which has several to many classes. We use the term factor to refer to vegetation type, vegetative cover, distance from water, and distance from roads. The term class refers to a specific category within a factor; for example, pinyon-juniper woodland, semi-arid shrub, and wet grassland are each a class of vegetation type.

Step 1. Assemble the literature (Optional). You have been asked to assist in this evaluation because of your personal experience and knowledge of Meadow Jumping mice. While not strictly necessary, it would be highly beneficial to the project and very helpful to me if you can provide literature citations to support your numbers. It has been found that expert-based models that did not include a literature review performed significantly worse than literature-based expert models (Clevenger et al. 2002. Expert-based models for identifying linkages. Conservation Biology 16:503-514). By providing literature citations, you help create a model that is more credible and more likely to influence conservation decisions. If there is no appropriate literature for some of your estimates, you may write "my unpublished data" or "my personal knowledge" in the cell asking for a citation.

Steps 2 - 6. Fill out the 5 worksheets (tabs at bottom) in the file. Instructions are found at the top of each worksheet.

1. Factor Weights: Indicate relative importance of the four factors for habitat use by Meadow jumping mice.

2. Score habitat suitability of each vegetation class.

3. Score habitat suitability of vegetative cover.

4. Score habitat suitability of distance from water.
5. Score habitat suitability of distance from roads.

Thank you again for your help!

* Adapted from Arizona Missing Linkages Parameterization Form (AML Ratings form01.xls), available at
http://www.corridordesign.org/downloads

1. Indicate the relative importance of the four factors (type, vegetative cover, distance from water, and distance from roads) for habitat use by Meadow Jumping mice. Enter a percentage weight between 0 and 100 for each of the four factors below. Fill out the Minimum and Maximum columns to indicate your uncertainty about the minimum and maximum weights that each factor might contribute. Do not worry about the fact that the max and min values will not sum to 100%.

2. It's impossible to completely separate the influences of vegetation from that of the presence water. After all, the presence of water directly effects soil type and moisture content, both of which help determine vegetation, and thus might be considered the most important *ultimate* factor. But for this model, consider the other side of the coin: Vegetation integrates the influence of factors like the presence of water in a way that makes it the most important *proximate* factor to animals. (In addition, for most species, there is more literature describing selection of vegetation types.) Set the weights for distance to water and roads to reflect only their *additional* influence on the animal within a vegetation type. If, for your focal species, the importance of these is entirely reflected in vegetation, give distance to water or distance to roads a score of 0%

3. If there are any essential factors that are not encompassed by vegetation type, vegetative cover, distance from water, or distance from roads, please make note of them on the last page, *Additional Factors*

Weights for each of the four factors

	Weight	Min	Max	Notes, Assumptions, Interpretations (optional)	
Vegetation Type	**55**	**30**	**80**		As an example, the placeholder values (which you will paste over) indicate a species for which Vegetative cover and Distance from Roads have no effect on habitat use, and the min/max values reflect a (ridiculously) high level of certainty.
Vegetative Cover	**0**	**0**	**0**		
Distance from Water	**40**	**30**	**75**		
Distance from Roads	**5**	**0**	**15**		
Must total 100%	**100**				

Patch Sizes. Please estimate (1) the smallest area of suitable habitat required to support 1 breeding group (e.g. the composite home range of a male-female pair) for 1 breeding season and (2) the smallest area of good habitat required to sustain an isolated breeding population for 5-10 years but not much longer (animals in an area this small would suffer loss of genetic diversity). You can estimate this area in hectares, acres, square km, or other units.

	Area	Units	Interpretation/Assumptions	Citation
Single breeding season	1.5	ha	or 200x400 m slightly larger than mean estimated by Schorr; estimate by wydfg	schorr 2003, other
10 breeding seasons				
Additional notes on space requirements				

Dispersal Distance. Please provide any information you may have about the dispersal distance of Meadow Jumping mice i.e., the distance a mouse moves from its place of birth to another area where it joins a breeding population. If you are unsure of dispersal distance for this species, please provide an estimate for a closely related species, or a species that is likely to have a similar dispersal distance. If possible, please provide an estimate of the typical dispersal distance (how far an average individual would disperse from its birthplace) and the maximum (the maximum distance you feel an individual might possibly disperse.)

Distance (Standard))	Distance (Max)	Units	Species	Interpretat	Citation
600	4500			distance moved	Schorr 2003
300					

VEGETATION TYPE

1. The cost should reflect *habitat suitability* of each class for the species; you may use *population density* or *fitness* as a measure of habitat suitability.

2. Land cover classes are grouped broadly by approximate National Land Cover Dataset category (green rows).

3. Please fill in columns for *Interpretations/Assumptions* and *Citation* **before** you assign the *Cost* in column D. You may cite unpublished data (but tell us the name and affiliation of the data owner). If you are relying on your expert opinion (as opposed to your own unpublished data), write "my expert opinion."

4. For your species, the literature may report preferences in classes broader than those listed, or may report for a particular vegetation type that resembles but is not identical to the classes available in this linkage area. This is where your expertise comes in, and it's why we asked *you* to do this!

5. In scoring vegetation, assign *cost* scores of 1-10 as follows:

   1-3: strongly preferred (1 being best)   4-5: usable but suboptimal habitat

   6-7: not breeding habitat, but perhaps occasionally used   8-10: strongly avoided (with 10 being worst)

6. Use the *Minimum* and *Maximum* columns to indicate your uncertainty about the cost for each class.

7. For description of land cover classes, please see the companion PDF document included in this e-mail.

Vegetation class	Habitat Suitability	Minimum	Maximum	Interpretation/Assumptions	Citation (Author-Date; for unpublished data, full name & affiliation)
Coniferous Forest (7)					
Lodgepole Pine	5	4	8	Trees are not as preferred as grasslands, but mjm have been found in forests.	Zapus 33
Ponderosa Pine	4	3	6	Ppine forests are often found upslope from riparian areas; proposed as day use areas for MJM	Zapus 27; Upslope?
Juniper-Pinion Pine	5	3	7	Juniper is liked by MJM, but these are often in drought prone areas	Zapus33
Douglas Fir	5	3	7	MJM occassionally associate with Douglas Fir	
Spruce-Fir	6	4	8	Some ties to white spruce, but these forests might be too high and dry	Zapus 33
Mixed Pine	5	3	7	Mixed pine species might make good habitat esp if deciduous species or shrubs are intermixed, but would likely not be preferred over grass or wetlands	Zapus31
Other Pine	5	3	7	See above	
Deciduous Forest (1)					
Aspen	2	1	3	Zhc was often trapped in aspen forests, esp upslope from streams	Zapus 31
Bur Oak	4	2	6	bur oak communities often upstream from ideal riparian areas, believed to used by mjm	Zapus 27
Deciduous Shrubs					
Gambel Oak Shrubland	3	2	7	More xeric and not as prefered as riparian veg, but contain many species associated with MJM. Often near riparian areas	Zapus 28, Zapus 31
Mountain Mahogany Shrubland	3	2	6	High diversity of preferred species and shrub cover, but drier and more upland make this less favorable	Zapus 33, Zapus 28, Zapus 27
Chokecherry-Serviceberry-Rose Shrub	3	2	6	"	"
Subalpine Shrubland	6	5	8	Good diversity of shrubs, but might be too high and dry for MJM	Zapus 33
Semi-Arid Shrub (2)					
Desert Scrub	7	5	9	Good vegetation cover, and diversity, but likely too dry for MJM	Zapus 33
Sagebrush Shrubland and Steppe	5	3	8	Sagebrush and mixed dry shrubs are often found in the areas surrounding wetland habitat and may be used by Zapus, but this habitat type may be too dry	Zapus 27
Grassland (6)					
Shortgrass	3	2	4	Grasslands are most preferred habitat after wetlands. MJM are eat lots of seeds	Zapus 31
Mixedgrass	2	1	4	higher diversity is preferred	Zapus 31/33
Tallgrass	3	2	4	see short grass	Zapus 31
Introduced Herbaceous Vegetation	5	3	7	still grass but tends to be less diverse and a poorer food supply	zapus 31 / my own assumptions
Wet Grassland	1	1	4	MJM have strong preferences for riparian shrub and grasslands/ assuming this includes wet grassland	Zapus 27, 33 esp Zapus 28
Montane Grassland	3	2	6	good species diversity, including sage; similar to mixed and short grass prarie	
Riparian Vegetation (3)					
Upper Montane Riparian	2	1	4	Good diversity of shrubs associaed with MJM, but might be too high elev	Zapus 27
Cottonwood-Willow Shrubland	1	1	3	ideal habitat found near water containing many of the species favored by MJM	Zapus 27, Zapus 28
Floodplain	1	1	3	ideal habitat found near water containing many of the species favored by MJM	Zapus 27, Zapus 28
Limited Vegetation (3)					
Alpine	9	9	10	favor sites with a high diversity of plant species, probably inadequate cover/food	Zapus 33 (Meaney) and others
Sparsely Vegetated	9	9	10	"	
Barren	10	10	10	"	
Agriculture (1)					
Agriculture	5	3	7	Prefer diverse veg cover; much lower numbers caught on ag land	zapus 33; zapus 9
Developed (3)					
Developed Low Intensity	7	6	8	Areas of higher human inhabitation would likely be avoided by mice, but might travel through	
Developed Medium Intensity	9	8	10	High human activity would be strongly avoided	
Developed High Intensity	10	9	10	"	
Other (2)					
Open Water	8	7	10	Mice cannot live on open water but proximaty to open water might be small patches of mouse habitat.	My own assumptions/NLCD Metadata
Snow/Ice	10	9	10	Areas of permanent snow/ice would be unsuitable for mice	My own assumptions

VEGETATIVE COVER

1. The cost should reflect *habitat suitability* of each class for Meadow Jumping mice; you may use *population density* or *fitness* as a measure of habitat suitability.

2. Please fill in columns for *Interpretations/Assumptions* and *Citation* **before** you assign the *Cost* in column D. You may cite unpublished data (but tell us the name and affiliation of the data owner). If you are relying on your expert opinion (as opposed to your own unpublished data), write "my expert opinion."

3. The literature may report preferences in classes broader than those listed, or more general preferences such as moderately dense. This is where your expertise comes in, and it's why we asked *you* to do this!

4. In scoring vegetation, assign scores of 1-10 as follows:

    1-3: strongly preferred (1 being best)   4-5: usable but suboptimal habitat

    6-7: not breeding habitat, but perhaps occasionally used   8-10: strongly avoided (with 10 being worst)

5. Use the *Minimum* and *Maximum* columns to indicate your uncertainty about the cost for each class.

6. For description of vegetative cover classes, please see the companion Word document included in this e-mail.

Vegetation class	Cost	Minimum	Maximum	Interpretation/Assumptions	Citation (Author-Date; for unpublished data,
Tree Cover					
>= 10 and < 20%					
>= 20 and < 30%					
>= 30 and < 40%					
>= 40 and < 50%					
>=50 and < 60%					
>= 60 and < 70%					
>= 70 and < 80%					
>= 80 and < 90%					
>= 90 and < 100%					
Shrub Cover					
>= 10 and < 20%					
>= 20 and < 30%					
>= 30 and < 40%					
>= 40 and < 50%					
>=50 and < 60%					
>= 60 and < 70%					
>= 70 and < 80%					
>= 80 and < 90%					
>= 90 and < 100%					
Herbacious Cover					
>= 10 and < 20%					
>= 20 and < 30%					
>= 30 and < 40%					
>= 40 and < 50%					
>=50 and < 60%					
>= 60 and < 70%					
>= 70 and < 80%					
>= 80 and < 90%					
>= 90 and < 100%					

Not completed because this factor was removed from the final analysis.

0. If you assigned a 0% weight to distance from water, *skip this page.*

1. Distance from water is measured as the Euclidean (straight-line) distance (in meters) from any 30x30 m pixel to the closest water source. Water sources included ponds, lakes, wetlands, streams and rivers. Think about how much the population density of Meadow Jumping mice, or probability of habitat use (including movement), would be affected by its proximity to water.

2. Please fill in the **upper** class boundaries as appropriate for your species (the lower bounds will change automatically). Add extra rows as needed.

3. In scoring distance from roads, assign scores of 1-10 as follows:

    1-3: strongly preferred (1 being best)   4-5: usable but suboptimal habitat

    6-7: not breeding habitat, but perhaps occasionally used   8-10: strongly avoided (with 10 being worst)

4. Use the *Minimum* and *Maximum* columns to indicate your uncertainty about the minimum and maximum costs for each class

5. Assume the farthest distance any location in the state is away from a water body is 15,000m.

6. As in the other sheets, your ratings must use a scale of 1-10. If you want to indicate that proximaty to water doesn't influence habitat suitability, you do so not by changing the 1-10 range, but by giving a low weight to Distance from Water on the "Factor Weights" worksheet (Page 1).

Distance from wates in METERS			Cost	Min	Max	Interpretation/Assumptions	Citation	
Lower	Upper							
0	50	:	1	1	2	Highly preferred habitat in close proximatity to	Zapus 13, 33 and Schorr	As an example, the place-holder
50	200	:	2	1	4	Typical home range of a MJM that lives near water		costs indicate that mice strongly prefer locations within 50m of
200	600	:	5	3	7	acceptable habitat, but less preferred		water, while strongly avoiding
600	1500	:	8	6	10	unsuitable habitat for MJM but within the distance an individual might move		locations more than 200m away from a water source.
1500	15000	:	10	9	10	Too far away to be used		
15000	15000	:						

DISTANCE FROM ROADS

0. If you assigned a 0% weight to distance from roads, *skip this page.*

1. Distance from roads is measured as the Euclidean (straight-line) distance (in meters) from any 30x30 m pixel to the closest road. Think about how much an animal's population density, or probability of habitat use (including movement), would be inhibited by its proximity to roads. This is necessarily somewhat more subjective than the previous ratings. Our GIS layer of roads excludes dirt roads, but includes all paved roads (but does not weight them by number of lanes).

2. Please fill in the **upper** class boundaries as appropriate for your species (the lower bounds will change automatically).

3. In scoring distance from roads, assign scores of 1-10 as follows:

    1-3: strongly preferred (1 being best)   4-5: usable but suboptimal habitat

    6-7: not breeding habitat, but perhaps occasionally used   8-10: strongly avoided (with 10 being worst)

4. Use the *Minimum* and *Maximum* columns to indicate your uncertainty about the minimum and maximum costs for each class

5. Assume the farthest distance any location in the state is away from a road is 15,000m.

6. As in the other sheets, your ratings must use a scale of 1-10. If you want to indicate that roads don't influence habitat suitability, you do so not by changing the 1-10 range, but by giving a low weight to Distance from Roads on the "Factor Weights" worksheet (Page 1).

Distance from roads in METERS						
Lower	Upper	Cost	Min	Max	Interpretation/Assumptions	Citation
0	50	: 9	7	10	Small mammals tend to avoid roads. This value also reflects the reluctance of Zapus to cross a road	
50	100	: 5	3	8	There is a possibility of a road-edge effect occuring with Zapus, but at this distance it is probably not strong enough to stop them from occupying this habitat	
100	200	: 5	2	7	" Also remember we are considering roads as a proxy for human activity	
200	1500	: 1	1	4	Would expect to see almost no impact from roads at this distance	
1500	15000	: 1	1	2		

As an example, the place-holder costs indicate that mice strongly avoids locations within 50m roads, while strongly preferring locations at least 200m away from roads.

APPENDIX B:

Vegetation Type

Information regarding the vegetation type came from the LANDFIRE Existing Vegetation Type dataset from USGS. The 91 categories of vegetation systems found in the original dataset were reclassified into 33 new landcover categories based on the Society of American Foresters (for trees and shrubs), Society for Range Management (for grasslands) and Landfire (anything else) designations. These were further grouped into 10 broader categories based roughly on National Landcover Dataset categories. Both the 10 new classes and the 33 subclasses are detailed below. A table of the 91 original categories grouped into the new classes and subclasses appears on pages 7-9.

Coniferous Forest (7)

Forested areas where at least 75% of the trees species retain their leave year-round. Shrub species commonly associated with coniferous forests include chokecherry (*Prunus virginiana),* Spirea (*Spiraea spp.) snowberry (Symphoricarpos spp.),* Rhododendron (*Rhododendron spp.),* Bearberry (*Arctostaphylos uva-ursi),* wild lilac (*Ceanothus veluntinus*), Twinflower (*Linnea borealis)* and various berry species (*Vaccinium spp*. and *Ribes spp.).*

- **Lodgepole Pine** – Forested areas dominated by Lodgepole pine (*Pinus contorta*) often in even-aged stands occurring following fire disturbance. The understory may be shrub, grass or bare. Sometimes other conifers or aspen stands are intermixed.
- **Ponderosa Pine** – Forested areas often found between the grasslands and the more mesic coniferous forests dominated by Ponderosa pine (*Pinus ponderosa*). Other shade tolerant conifers such as Junipers (*Juniperus spp.),* Douglas fir (*Pseudotsuga menziesii*) and Lodgepole pine may be interspersed in the canopy. The savannas have an understory dominated by fire-resistant grasses, while the woodlands have an understory of deciduous shrubs. In the Black Hills area, deciduous species including aspen, birch and bur oak may codominate with the pines.
- **Juniper-Pinion Pine** – Coniferous forest systems generally found above 1500m in areas often subjected to severe climatic events including frost and droughts. Dominated by Junipers and/or Pinyon Pine (*Pinus edulis* and *P. monophylla*).
- **Douglas Fir -** Forests found throughout the central Rocky Mountain region dominated by Douglas fir. True firs are not present but pines and spruce may also occur.
- **Spruce-Fir** – High elevation forests dominated by a mix of spruce (*Picea engelmannii* and P. *glauca*) and firs (*Abies lasiocarpa*). Other conifers maybe intermixed and cold tolerant understory shrubs such as *Rhododendron spp*. and *Vaccinium spp*. are present.
- **Mixed Pine –** Coniferous forests found in the montane zone containing a mix of pine species and other conifers. Douglas fir and White fir are the most common, but as many as seven different species of conifer may be found in the same forest

- **Other Pine -** Coniferous forests in the rocky Mountains not dominated by any of the above species. Includes forests dominated by Whitebark pine (*Pinus albicaulis*), Bristlecone pine (*Pinus longaeva*), and/or Limber pine (*Pinus flexilis*). A shrub layer may be present.

Deciduous Forest (2)

Areas where deciduous trees are dominate. Often with interspersed conifers and a moderate woody understory. Commonly associated shrub species include serviceberry (*Amelanchier spp.*), chokecherry (*Prunus virginiana*), rose (*Rosa spp.),* juniper (*Juniperus spp.),* snowberry (*Symphoricarpos sp.p*), various berry species (*Rubus spp.).*

- **Aspen –** Woodland areas dominated by aspens (*Populus tremuloides*) commonly found on montane slopes and plateaus in the Western US. Various conifer species are interspersed throughout the forest and will eventually become dominant as the system ages.
- **Bur Oak –** Deciduous forests dominated by Bur Oak (*Quercus macrocarpa*), but also including aspen and ash (*Fraxinus spp*). Often found near Ponderosa pine forests.

Deciduous Shrubs (4)

Areas containing a moderate to dense cover of woody shrubs, often found in small patches between grasslands or pine forests in areas unsuitable for tree growth. Often a mix of deciduous species dominates with the genera *Amelanchier, Ribes, Rosa* and *Rubus* appearing in almost all deciduous shrublands.

- **Gambel Oak Shrubland** – Shrublands found in the foothills and lower mountain slopes where Gambel oak (*Quercus gambelii*) is typically dominant or codominant with other deciduous shrub species.
- **Mountain Mahogany Shrubland –** Shrublands occurring on steep rocky slopes dominated by Mountain mahogany (*Cercocarpus ledifolius*) often with sage and snowberry are common with a few interspersed trees usually pines or junipers.
- **Chokecherry-Serviceberry-Rose Shrub** – Deciduous shrublands often found in rocky areas including talus slopes and dry drainages. A true mix of shrub species with multiple species codominating including Mountain mahogony (*Cercocarpus montanus*), serviceberry (*Amelanchier spp.),* sumac (*Rhus spp.),* and rose (*Rosa spp.)*
- **Subalpine Shrubland** – Deciduous shrublands found in the moist soils of the upper montane and lower subalpine zones of the Rockies. Consists primarily of woody shrubs including buckthorn (*Rhamnus spp.),* Mountain ash (*Sorbus spp.)* and huckleberry (*Vaccinium spp.)*
-

Semi-Arid Shrub (2)

Semi-arid areas dominated by shrubs, often with bunch graminoids and forbs in between. Generally occurs in harsher environments often rocky and/or windswept. Soils are often salty and alkaline. saltbush (*Atriplex spp*.) and/or sage (*Artemisia spp.)* dominate the shrub layer, but other species may be present including the genera: *Grayia, Lycium, Ephedra, Ericameria*. Herbaceous species include Blue

bunchgrass (*Pseudoroegneria spicata*), Blue grama (*Bouteloua gracilis*), Indian ricegrass (*Achnatherum hymenoides*), Thickspike wheatgrass (*Elymus lanceolatus*), Western wheatgrass (*Pascopyrum smithii*), and Sandberg bluegrass (*Poa secunda*).

- **Desert Scrub** – open canopied shrublands found in arid regions of the Great Plains were alkaline, saline soils are predominant. Typically, dominanted by one or more species of saltbush. Sage and other shrubs may be present or codominant.
- **Sagebrush Shrubland and Steppe** – A mix of herbaceous vegetation and shrubs with the shrub layer being dominated by one or more species of sage. More montane areas may also contain snowberry (*Symphoricarpos spp.),* serviceberry (*Amelanchier spp.),* Morman tea (*Ephedra spp.)* and *Ribes spp*.

Grassland (6)

Open areas dominated by grasses and forbs. Shrubs and/or tree species may be present, but these comprise only a small proportion of the overall canopy cover. Grasses may be annuals, bi-annuals or perennials and often a mix of all three is present.

- **Shortgrass** – Open grassland dominated by sod-forming short grasses, especially Blue grama (*Bouteloua gracilis*) and buffalograss *(Bouteloua dactyloides*). Other short grass species including the genera Aristida*, Buchloe, Hesperostipa, Koeleria, Pascopyrum* and *Sporobolus* may also be present.
- **Mixedgrass** – A mixed grassland located between the shortgrass and tallgrass praires of the Great Plains containing a mix of species from both. Dominate species include Western wheatgrass (*Pascopyrum smithii*), Blue grama, and Little bluestem (*Schizachyrium scoparium*). Occasionally contains forb species mostly *Carex spp.* and isolated patches of Bur oak (*Quercus macrocarpa).*
- **Tallgrass** – open grassland dominated characterized by tall prairie grasses. Often found in patches interspersed in mixed grass prairie with soil types ranging from loamy to sandy. Big bluestem (*Andropogon gerardi*) dominates the more mesic areas while sandy areas are dominated by Prairie sandreed (*Calamovilfa longifolia*).
- **Introduced Herbaceous Vegetation** – grasslands where the vegetative composition has been significantly altered or disturbed by the introduction of non-native species. Such non-native species include Broadleafed pepperweed (*Lepidium latifolium*), Yellow sweetclover (*Melilotus officinalis*), Japanese brome (*Bromus japonicas*) and Canadian thistle (*Cirsium arvense*).
- **Wet Grassland** – grassland vegetation found in floodplains, depressional wetlands and along lake borders in the Great Plains. They grow on relatively impermeable, clayey soils that are periodically inundated and often saline. Common species include Eastern gamagrass (*Tripsacum dactyloides*), Buffalograss, Western wheatgrass, spikerushes (*Eleocharis spp.*) and cordgrass *(Spartina spp.).* The NLCD classifications Herbaceous wetland, Herbaceous semi-wet and Herbaceous semi-dry were also placed in this category.

- **Montane Grassland** – grasslands commonly found in the foothills and valleys of the Rocky Mountains. They have a similar species composition to short and mixed grass prairie with scattering of shrubs, usually sage (*Artemisia spp.*), forbs and lichen.

Riparian Vegetation (3)

Vegetation communities found in association with perennial water sources including lakes, ponds, rivers, streams and seeps. Cottonwood (*Populus spp.*) and willows (*Salix spp.*) are common in these moist soil plant communities.

- **Upper Montane Riparian** – A vegetation community found bordering perennial water sources in the upper montane regions of the Rocky Mountains. Subalpine fir (*Abies lasiocarpa)* and Engelmann Spruce (*Picea engelmannii*) are often dominate with other higher elevation conifirs, aspens and cottonwoods are also common, but not usually dominant. A shrub layer composed of alder (*Alnus spp.*), willow (*Salix spp.*), birch (*Betula spp.*) and other deciduous shrubs is usually present
- **Cottonwood-Willow Shrubland** – Tree dominated communities with a diverse shrub layer. Willow and cottonwood are the most common dominant trees species, but alder, birch, aspen (*Populus tremuloides*), Box elder (*Acer negundo*), Douglas fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*) are also common.
- **Floodplain** – Vegetation communities associated with the floodplains surrounding large rivers and subject to periodic flooding. Cottonwood (*Populus deltoids*) and willow with a prominent layer of tallgrasses also present. Prevalent shrub species include chokecherry (*Prunus virginiana*), serviceberry (*Amelanchier spp.*), dogwood (*Cornus spp.*), snowberry *(Symphoricarpos spp.),* hawthorn (*Crataegus spp.),* and rose (*Rosa spp.*)

Limited Vegetation (3)

Areas with a minimal vegetative cover due either to human disturbances or harsh environments poorly suited toward plant life.

- **Alpine** –vegetation communities found above 2000m in elevation in areas which tend to be harsh, windswept and often snow covered. The predominant vegetation is short clump grasses and forbs and occasionally dwarf shrubs usually willows (*Salix spp.*) rarely above .5m in height.
- **Sparsely Vegetated** – Areas with less than 10% total vegetation usually in scattered clumps. Cliff faces, rock outcrops, badlands etc. Tend to be windswept and rugged.
- **Barren** – areas of bare rock, gravel sand etc with little to no vegetation. Includes old quarries and strip mines.

Agricultural (1)

Areas used predominately for agricultural purposes.

- **Agricultural** – lands used for food production including fenced pastures, hay and grasses, close grown crops such as wheat, rice, oats, and barley; and row crops including corn, soy, and beans.
-

Developed (3)

Areas where vegetation is mixed with constructed materials comprising > than 20% of the total land cover. These areas have a moderate to high level of human disturbance and much of the vegetation is altered or disturbed.

- **Developed Low Intensity** – areas where impervious surfaces comprise between 20 and 50% of the total land cover. For our purposes, all other Landfire Developed categories (ie. Developed Upland Shrubland) are placed in this category. Roads are also classified as Low Intensity because their effect is more specifically address with the distance to road factor.
- **Developed Medium Intensity** – areas where impervious surfaces comprise between 50 and 80% of the total land cover.
- **Developed High Intensity** – areas where impervious surfaces comprise between 80 and 100% of the total land cover.

Other (2)

Any area not falling in any of the above categories.

- **Open Water –** Areas with less than 25% land cover.
- **Snow/Ice –** Areas characterized by year-long presence of ice and/or snow

APPENDIX C:

Vegetation reclassification from original LANDFIRE dataset to new classes and subclasses used in this study.

NEW CLASS	NEW SUBCLASS	ORIGINAL LANDFIRE CATEGORY
Agriculture	Agriculture	Agriculture-Cultivated Crops and Irrigated Agriculture
		Agriculture-Pasture and Hay
		NASS-Close Grown Crop
		NASS-Pasture and Hayland
		NASS-Row Crop
Semi-arid Shrub	Desert Scrub	Inter-Mountain Basins Greasewood Flat
		Inter-Mountain Basins Mat Saltbush Shrubland
		Inter-Mountain Basins Mixed Salt Desert Scrub
		Inter-Mountain Basins Semi-Desert Shrub-Steppe
	Sagebrush Shrubland and Steppe	Artemisia tridentata ssp. vaseyana Shrubland Alliance
		Colorado Plateau Mixed Low Sagebrush Shrubland
		Inter-Mountain Basins Big Sagebrush Shrubland
		Inter-Mountain Basins Big Sagebrush Steppe
		Inter-Mountain Basins Montane Sagebrush Steppe
		Northwestern Great Plains Shrubland
		Southern Colorado Plateau Sand Shrubland
		Western Great Plains Sandhill Steppe
		Wyoming Basins Dwarf Sagebrush Shrubland and Steppe
Coniferous Forest	Douglas Fir	Middle Rocky Mountain Montane Douglas-fir Forest and Woodland
	Juniper-Pinion Pine	Colorado Plateau Pinyon-Juniper Woodland
		Inter-Mountain Basins Juniper Savanna
		Southern Rocky Mountain Juniper Woodland and Savanna
		Southern Rocky Mountain Pinyon-Juniper Woodland
	Lodgepole Pine	Rocky Mountain Lodgepole Pine Forest
		Rocky Mountain Poor-Site Lodgepole Pine Forest
	Mixed Pine	Abies concolor Forest Alliance
		Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland
		Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland
	Other Pine	Northern Rocky Mountain Subalpine Woodland and Parkland
		Rocky Mountain Foothill Limber Pine-Juniper Woodland
		Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland

	Ponderosa Pine	Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna Southern Rocky Mountain Ponderosa Pine Savanna Southern Rocky Mountain Ponderosa Pine Woodland
	Spruce-Fir	Northwestern Great Plains Highland White Spruce Woodland Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland
Deciduous Forest	Aspen	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland Rocky Mountain Aspen Forest and Woodland
	Bur Oak	Western Great Plains Dry Bur Oak Forest and Woodland
Deciduous Shrub	Chokecherry-Serviceberry-Rose Shrub	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland Rocky Mountain Lower Montane-Foothill Shrubland
	Subalpine Shrubland	Northern Rocky Mountain Subalpine Deciduous Shrubland
	Gambel Oak Shrubland	Quercus gambelii Shrubland Alliance Rocky Mountain Gambel Oak-Mixed Montane Shrubland
	Mountain-Mahogany Shrubland	Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland
Developed	Developed Low Intensity	Developed-Herbaceous Wetland Vegetation Developed-Low Intensity Developed-Open Space Developed-Roads Developed-Upland Deciduous Forest Developed-Upland Evergreen Forest Developed-Upland Herbaceous Developed-Upland Shrubland Developed-Woody Wetland Vegetation
	Developed Medium Intensity	Developed-Medium Intensity
	Developed High Intensity	Developed-High Intensity
Grassland	Introduced Herbaceous Vegetation	Introduced Upland Vegetation-Annual and Biennial Forbland Introduced Upland Vegetation-Annual Grassland Introduced Upland Vegetation-Perennial Grassland and Forbland
	Mixedgrass	Central Mixedgrass Prairie Northwestern Great Plains Mixedgrass Prairie Western Great Plains Foothill and Piedmont Grassland

	Montane Grassland	Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland
		Northern Rocky Mountain Subalpine-Upper Montane Grassland
	Shortgrass	Inter-Mountain Basins Semi-Desert Grassland
		Western Great Plains Shortgrass Prairie
	Tall Grass	Western Great Plains Sand Prairie
		Western Great Plains Tallgrass Prairie
	Wet grassland	Eastern Great Plains Wet Meadow-Prairie-Marsh
		Herbaceous Semi-dry
		Herbaceous Semi-wet
		Herbaceous Wetlands
		Western Great Plains Depressional Wetland Systems
Limited Vegetation	Alpine	Rocky Mountain Alpine Dwarf-Shrubland
		Rocky Mountain Alpine Fell-Field
		Rocky Mountain Alpine Turf
		Rocky Mountain Subalpine-Montane Mesic Meadow
		Southern Rocky Mountain Montane-Subalpine Grassland
	Barren	Barren
	Sparsely Vegetated	Inter-Mountain Basins Sparsely Vegetated Systems
		Rocky Mountain Alpine/Montane Sparsely Vegetated Systems
		Western Great Plains Sparsely Vegetated Systems
Riparian Vegetation	Cottonwood-Willow	Inter-Mountain Basins Montane Riparian Systems
		Rocky Mountain Montane Riparian Systems
	Floodplain	Introduced Riparian Vegetation
		Western Great Plains Wooded Draw and Ravine
		Western Great Plains Floodplain Systems
	Upper Montane Riparian	Rocky Mountain Subalpine/Upper Montane Riparian Systems
Other	Snow-Ice	Snow-Ice
	Water	Open Water

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APPENDIX D:

Larger copies of all of the habitat suitability models created during this study.
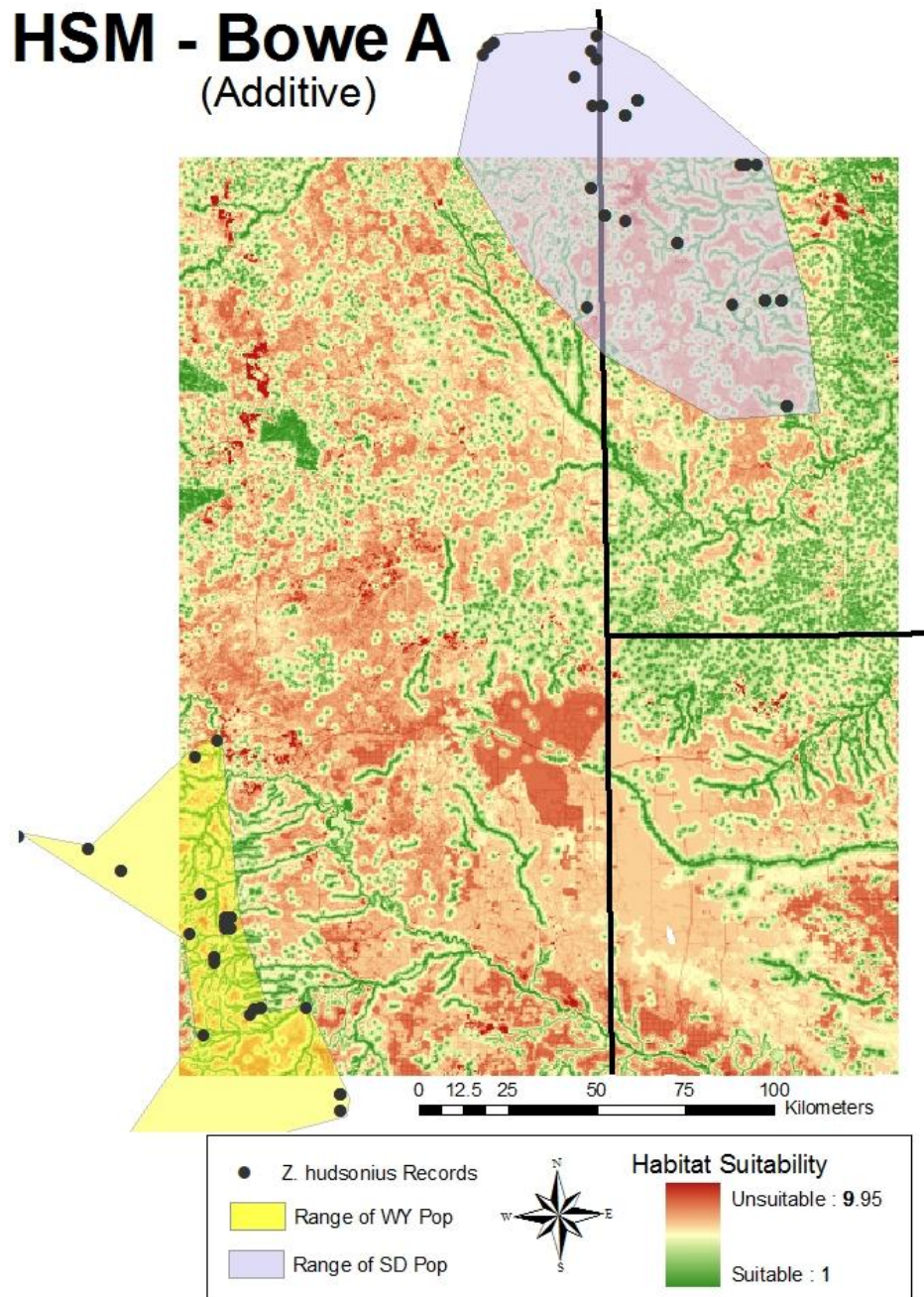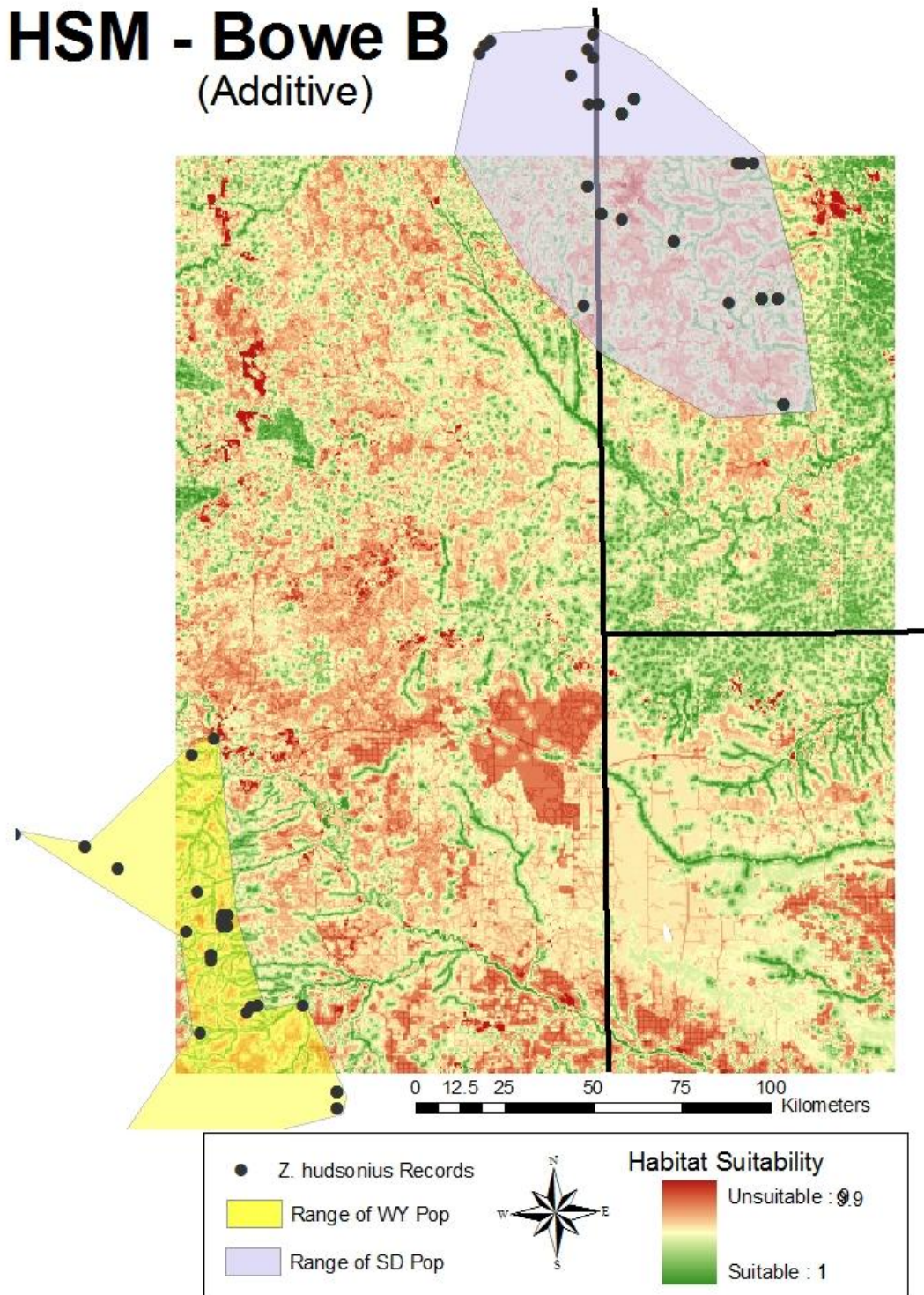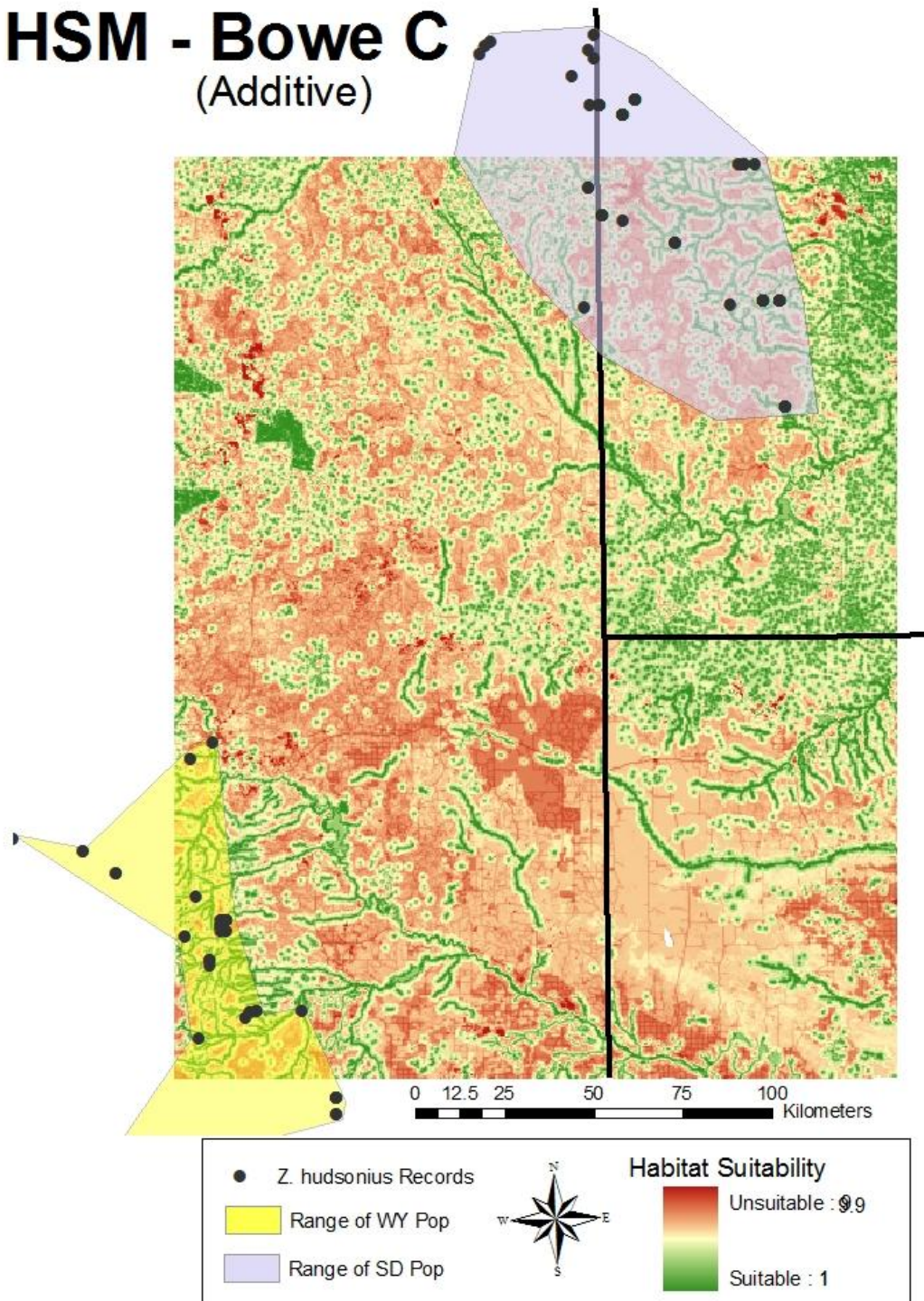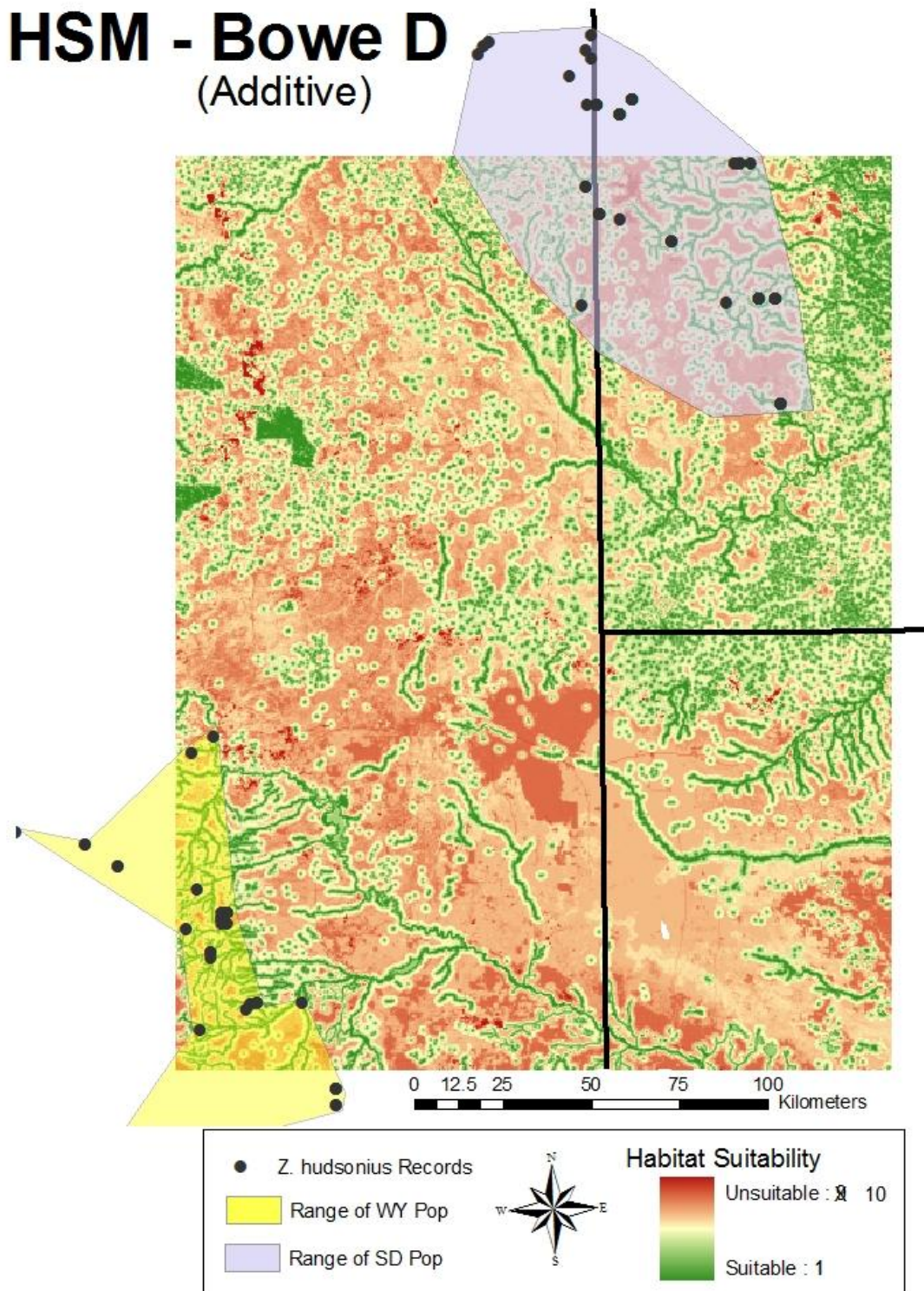In order of appearance.

Figure 3A: HSM created using suitability values derived from a literature review by the author and factor weights of vegetation type (55), distance from water (40) and distance from roads (0). Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range of *Z. h. preblei.* From page 54.

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Figure 3B: HSM created using suitability values derived from a literature review by the author and factor weights of vegetation type (60), distance from water (30) and distance from roads (10). Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range of *Z. h. preblei.* From page 54.
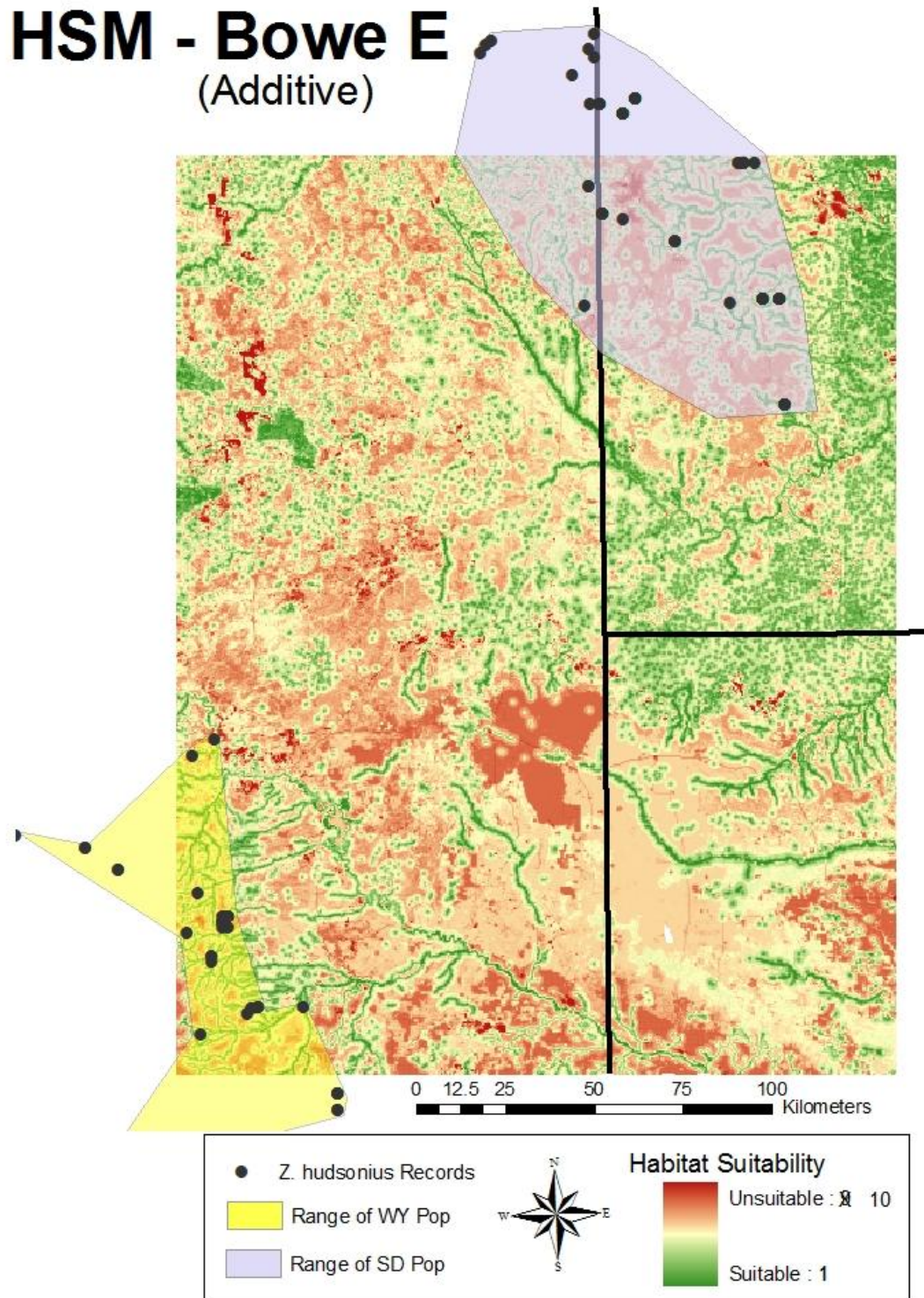
Figure 3C: HSM created using suitability values derived from a literature review by the author and
factor weights of vegetation type (45), distance from water (45) and distance from roads (10).
Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat.
Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range
of *Z. h. preblei*. From page 54.

Figure 3D: HSM created using suitability values derived from a literature review by the author and factor weights of vegetation type (50), distance from water (50) and distance from roads (0). Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range of *Z. h. preblei.* From page 54.

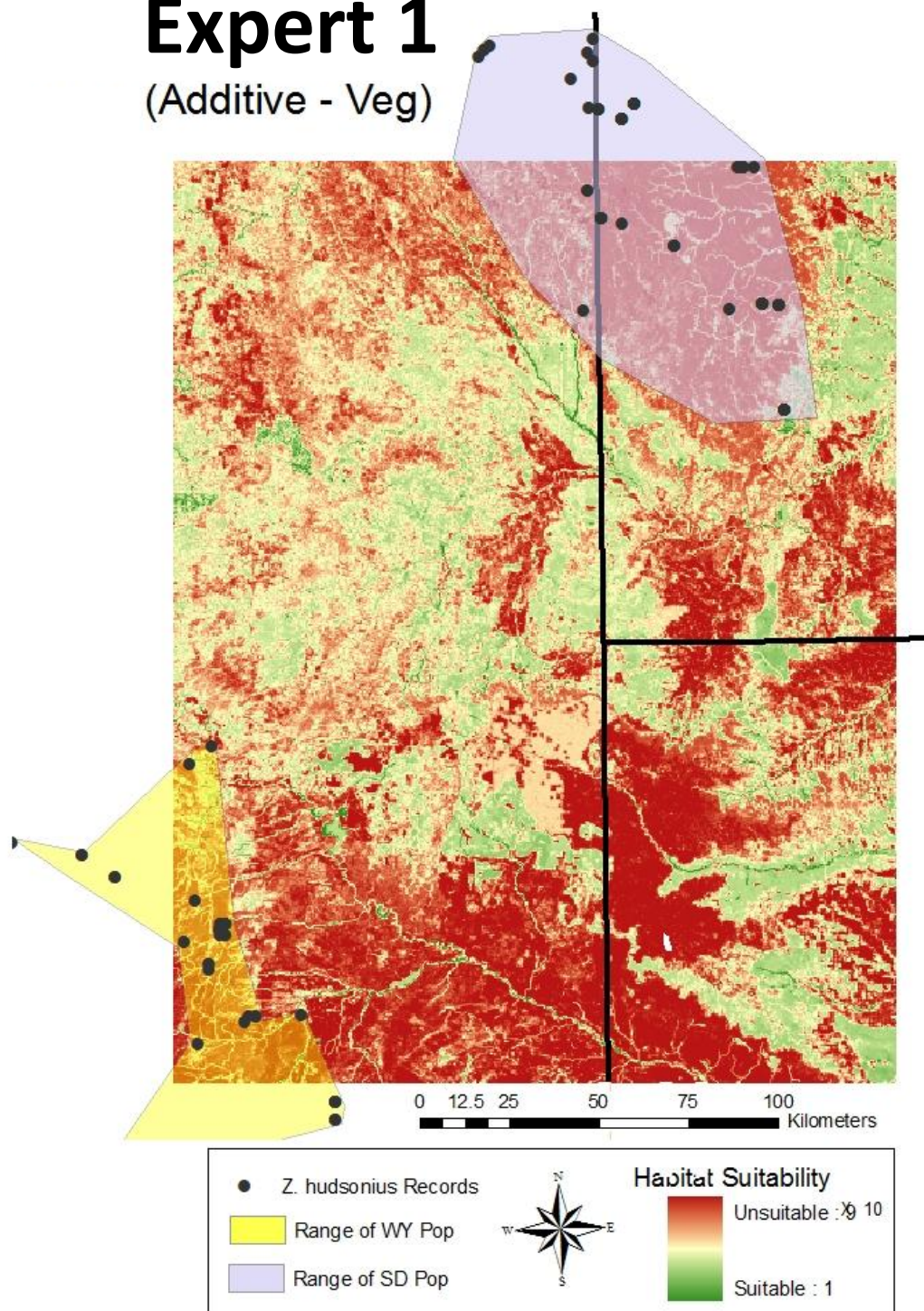Figure 3E: HSM created using suitability values derived from a literature review by the author and factor weights of vegetation type (65), distance from water (35) and distance from roads (0). Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range of *Z. h. preblei.* From page 54.
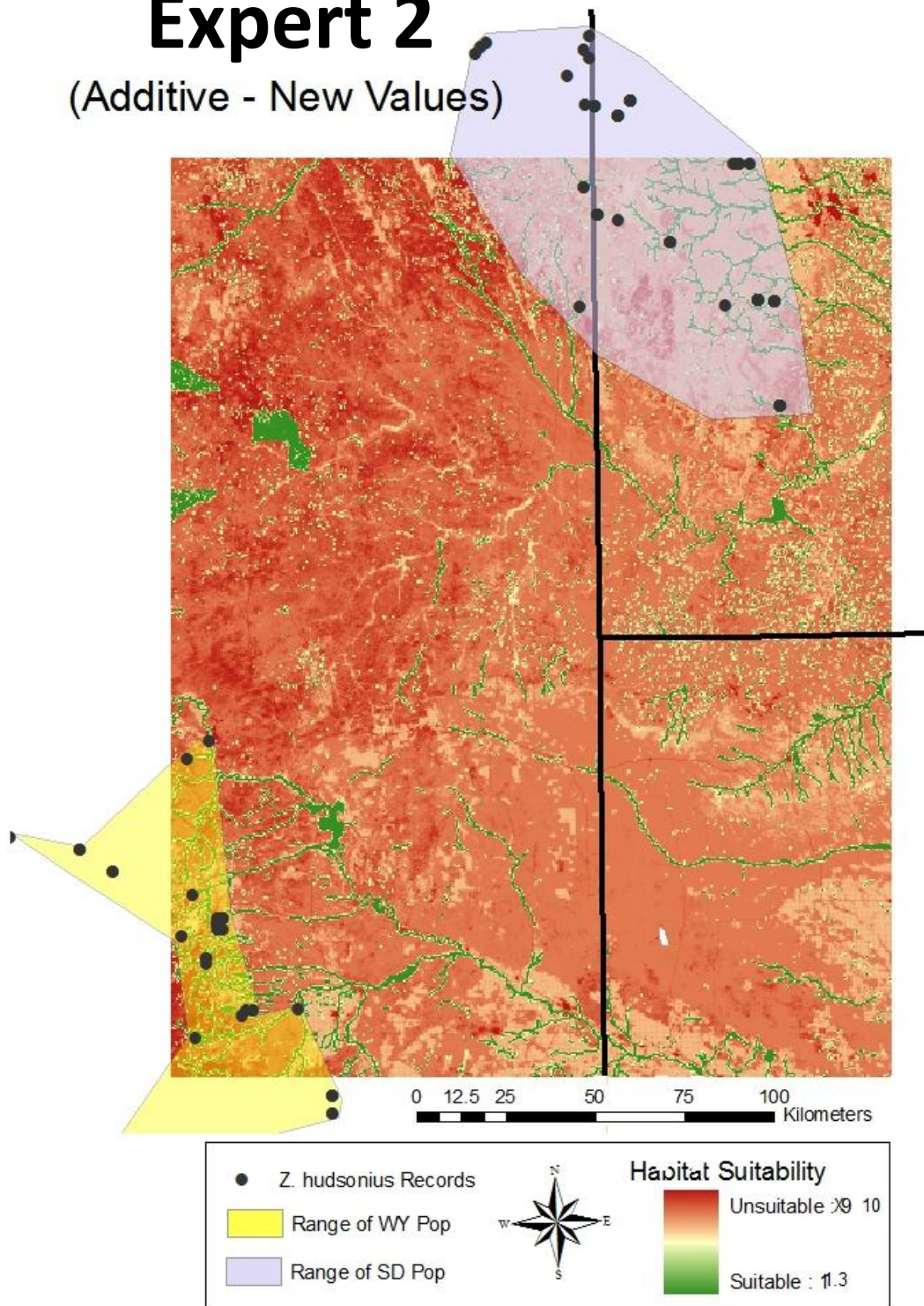
104

Figure 5A: HSM created using suitability values and factor weights assigned by Expert 1 via parameter evaluation surveys. Factor weights = vegetation type (60), distance from water (40) and distance from roads (0). Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range of *Z. h. preblei*. From page 63.
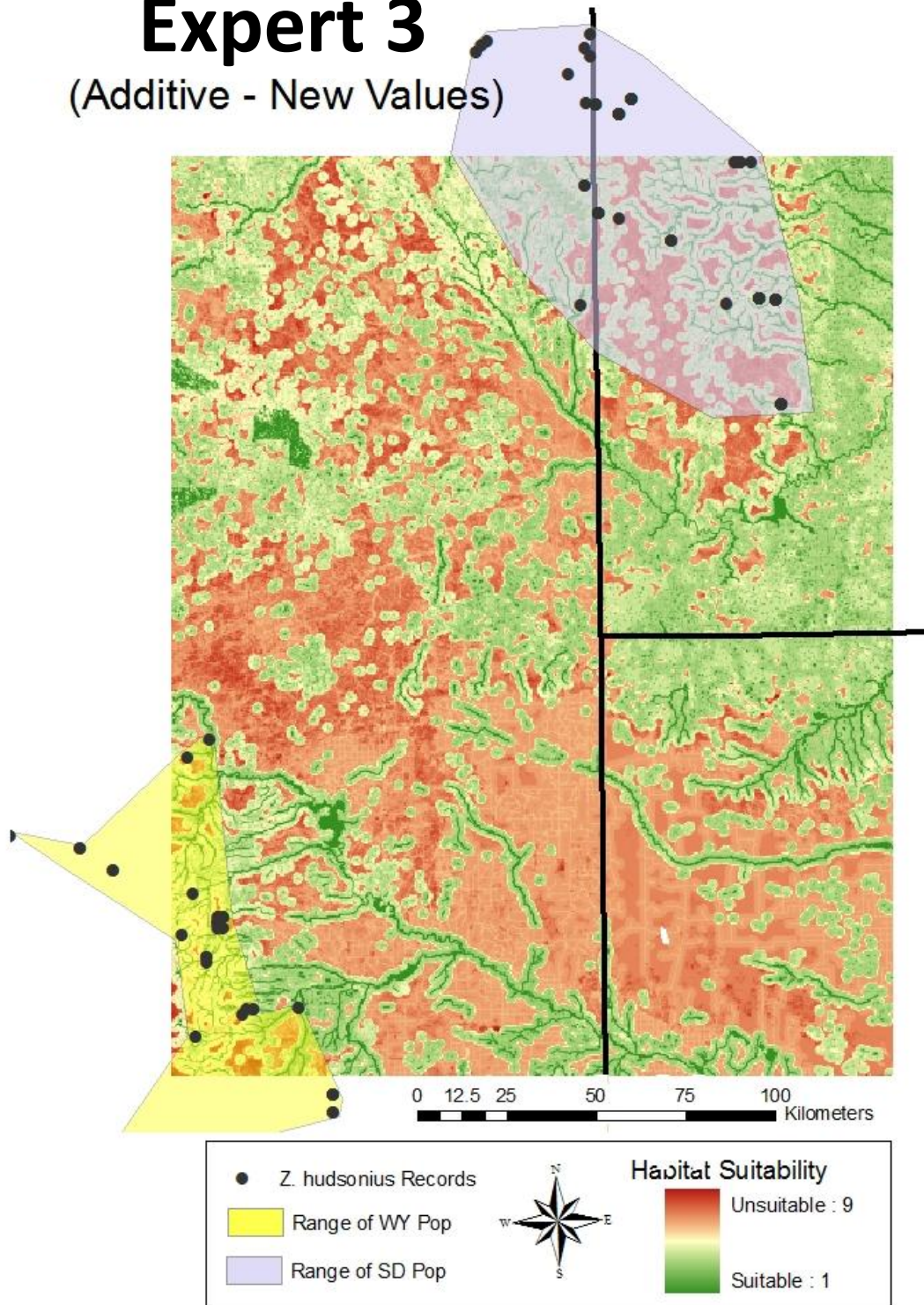
Figure 5B: HSM created using suitability values and factor weights assigned by Expert 2 via
parameter evaluation surveys. Factor weights = vegetation type (30), distance from water
(70) and distance from roads (0). Green areas indicate highly suitable habitat and red areas
indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the
yellow indicates the known range of *Z. h. preblei*. From page 63. 106

Figure 5D: HSM created using suitability values and factor weights assigned by Expert 3 via parameter evaluation surveys. Factor weights = vegetation type (40), distance from water (55) and distance from roads (5). Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range of *Z. h. preblei*. From page 63. 107
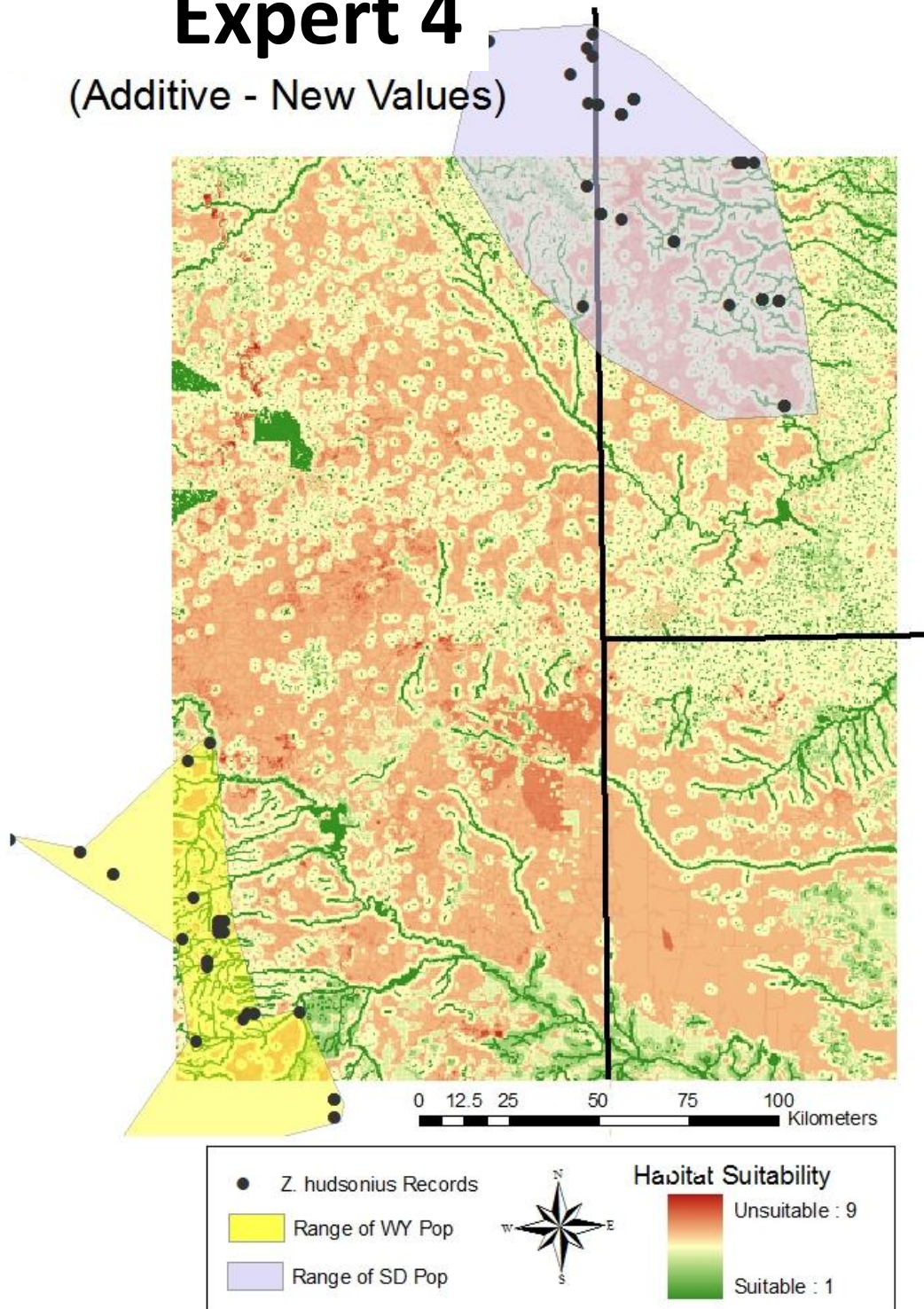
Figure 5E: HSM created using suitability values and factor weights assigned by Expert 4 via parameter evaluation surveys. Factor weights = vegetation type (30), distance from water (60) and distance from roads (10). Green areas indicate highly suitable habitat and red areas indicate highly unsuitable habitat. Blue indicates the known range of *Z. h. campestris* and the yellow indicates the known range of *Z. h. preblei*. From page 63.
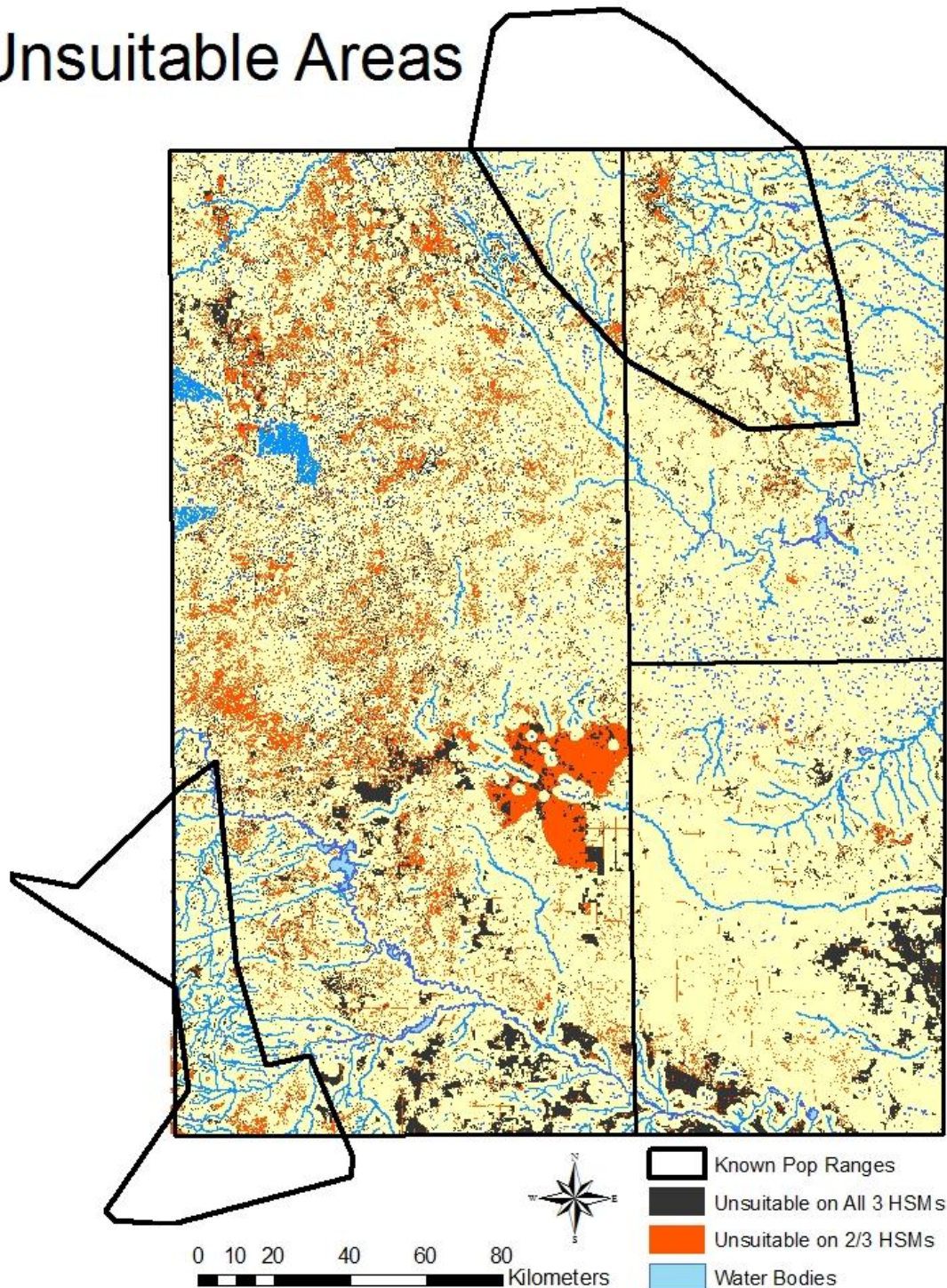
Unsuitable Areas

Figure 7: Portions of the analysis area classified as highly suitable on all three HSMs or
   moderately suitable on all three HSMs (in black). Portions of the analysis area classified as
   highly suitable on 2 of 3 HSMs or moderately suitable on 2 of 3 HSMs (in green). Known
   population ranges of Z. hudsonius in southeast WY and western SD are outlined in black.
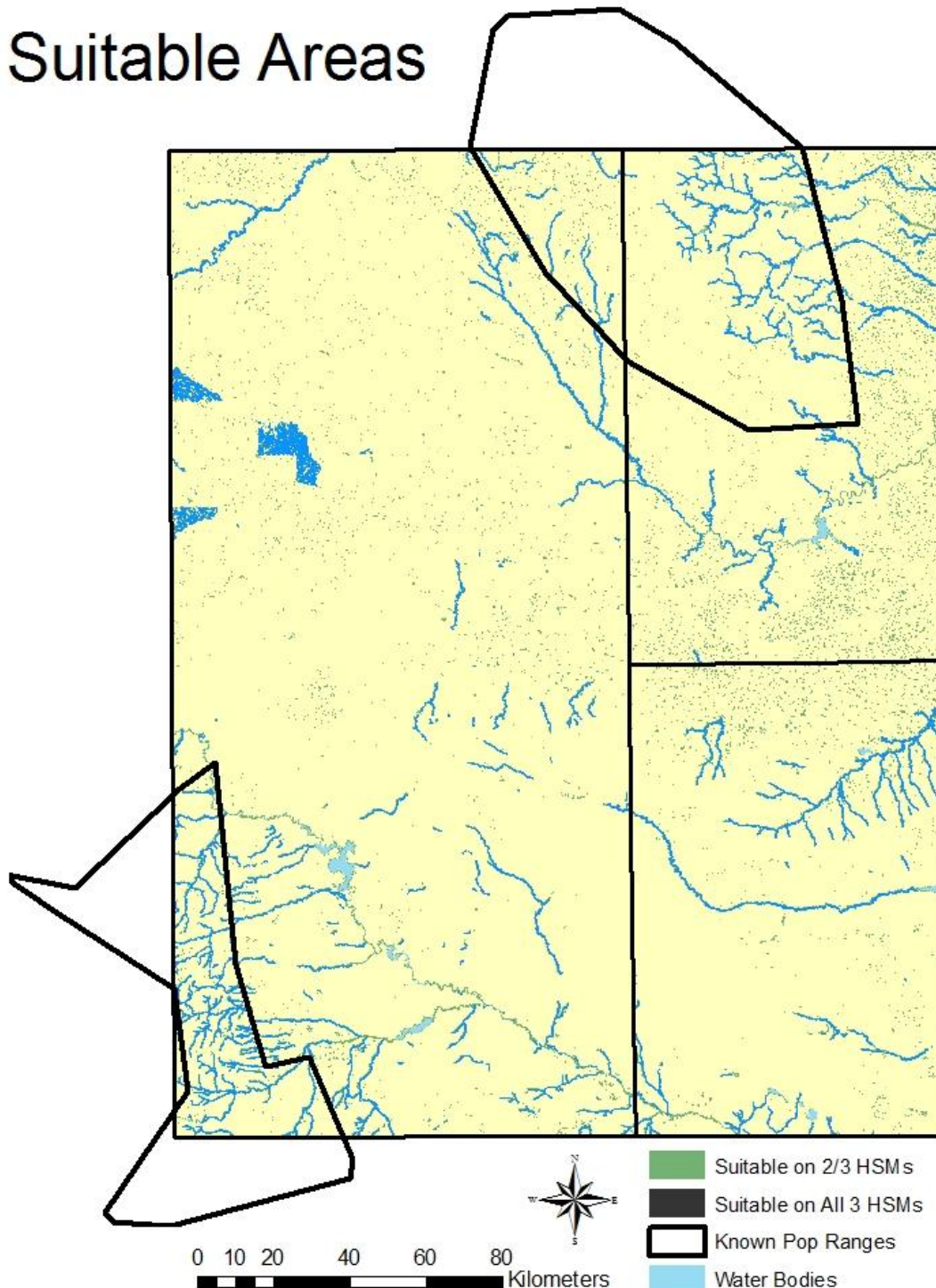   From page 66.

Figure 7: Portions of the analysis area classified as highly suitable on all three HSMs or moderately suitable on all three HSMs (in black). Portions of the analysis area classified as highly suitable on 2 of 3 HSMs or moderately suitable on 2 of 3 HSMs (in green). Known population ranges of Z. hudsonius in southeast WY and western SD are outlined in black. From page 67.
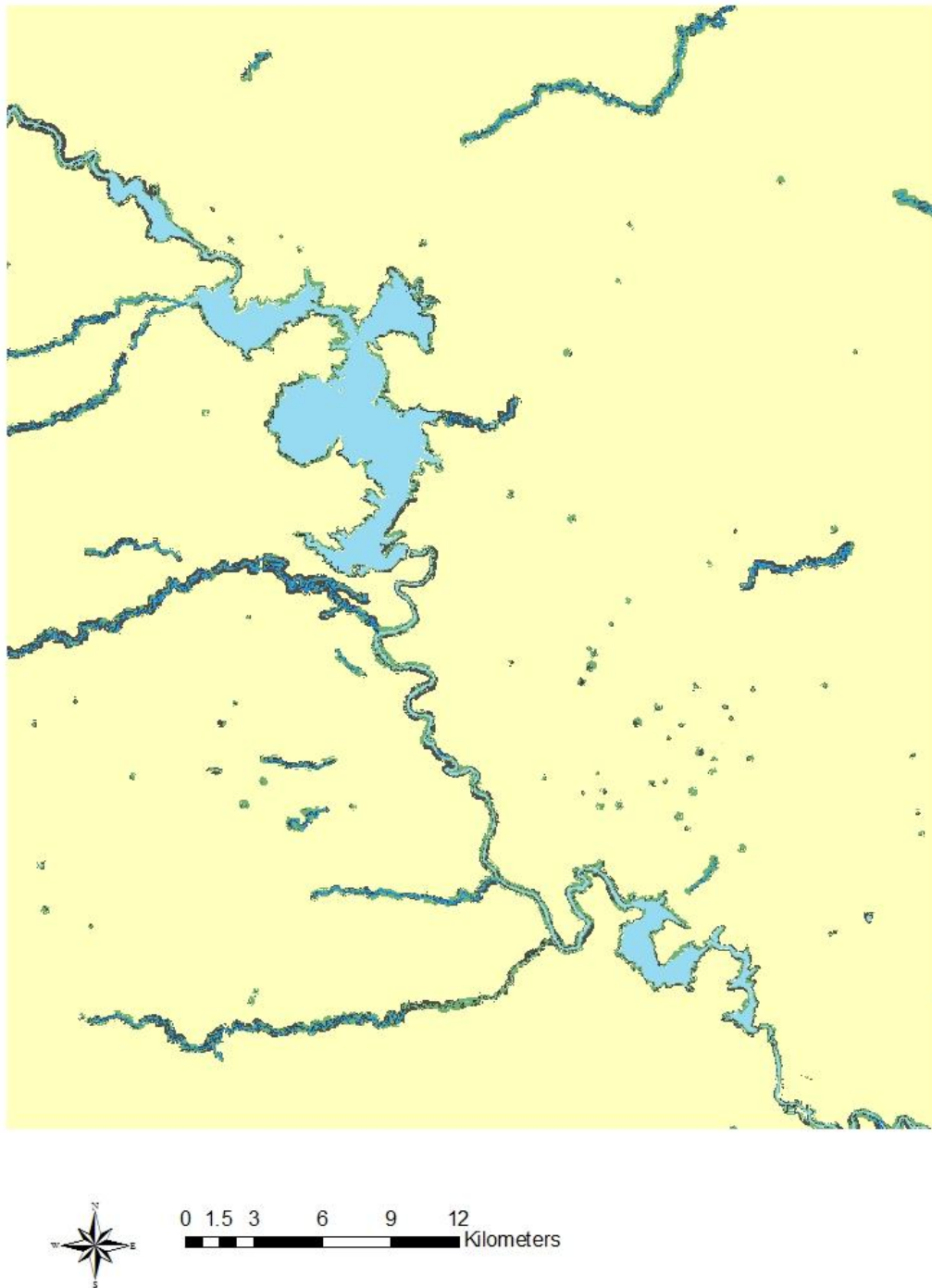
Figure 9A: Close-up of the area surrounding the Glendo and Guernsey reservoirs, one of the two recommended sites for future trapping studies of *Z. hudsonius*. Portions of the analysis area classified as highly suitable on all three HSMs or moderately suitable on all three HSMs are shown in black. Portions of the analysis area classified as highly suitable on 2 of 3 HSMs or moderately suitable on 2 of 3 HSMs are shown in green. From page 73

Figure 9B: Close-up of the area surrounding the town of Lusk, WY, one of the two recommended sites for future trapping studies of *Z. hudsonius.* Portions of the analysis area classified as highly suitable on all three HSMs or moderately suitable on all three HSMs are shown in black. Portions of the analysis area classified as highly suitable on 2 of 3 HSMs or moderately suitable on 2 of 3 HSMs are shown in green. From page 73.
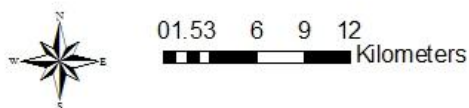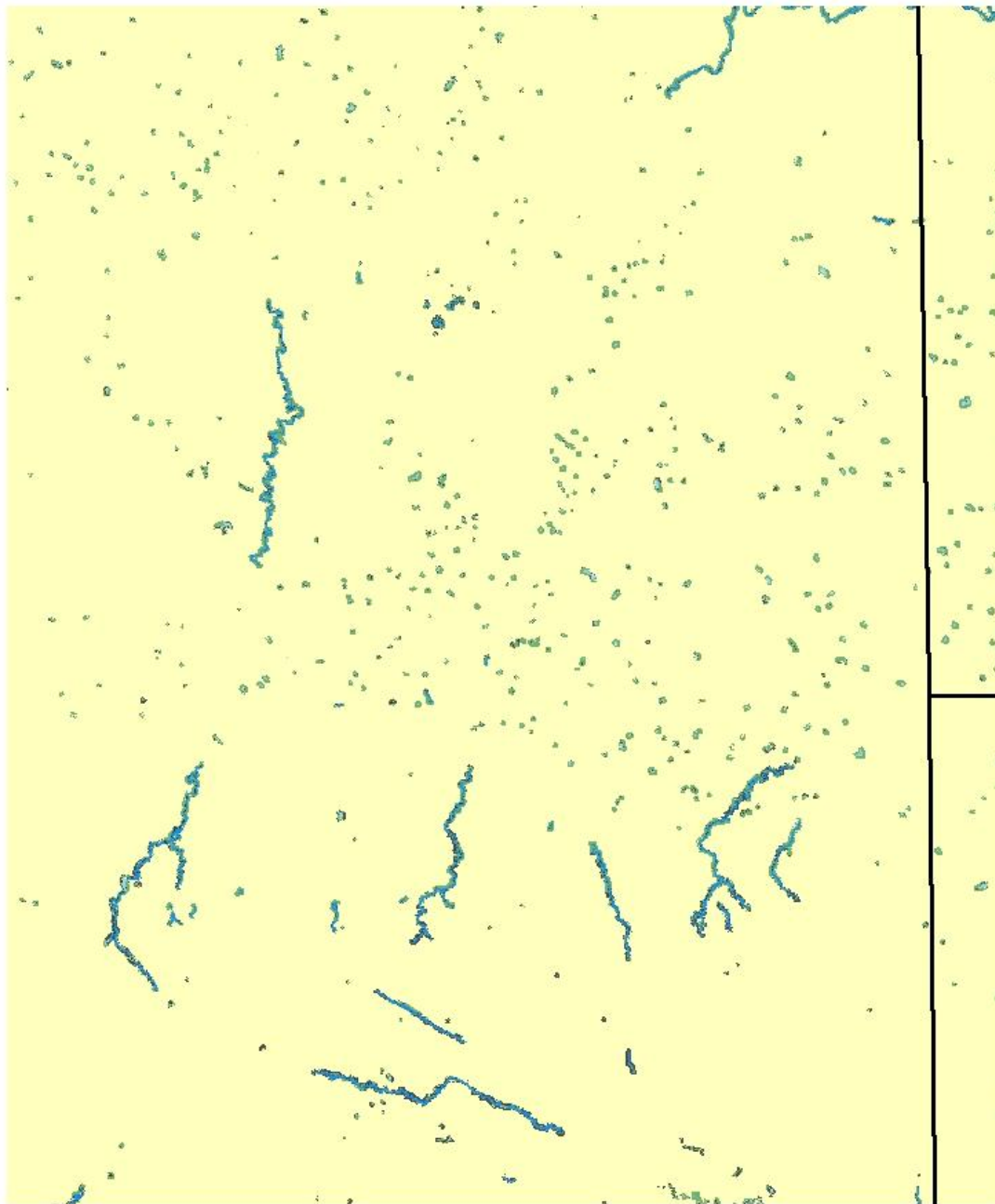
Amanda L. Bowe

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University Park, PA 16802   Honey Brook, PA 19344
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EDUCATION

The Pennsylvania State University, University Park, PA
Bachelor of Science, Wildlife and Fisheries Science, Wildlife Option   May 2011
Minor, Geographic Information Science

Schreyer Honors College at The Pennsylvania State University
Undergraduate Thesis (In-Progress) – Modeling Habitat Suitability and Landscape Resistance for
Meadow Jumping Mice in the Western Great Plains

James Cook University, Townsville, Queensland, AU
One semester study abroad experience in Queensland, Australia

RELATED CAREER EXPERIENCE

Tri-State Bird Rescue and Research, Newark, DE
Bird Care Intern   July- August 2010
- Provided care and feeding of injured, orphaned and oiled birds
- Monitored and reported bird health and behavior
- Assisted veterinarians with diagnosis and treatment
- Supervised volunteer caretakers

Rocky Mountain Bird Observatory, Black Hills, SD
Field Technician   May – July 2009
- Conducted point counts in various habitats throughout Black Hills National Forest
- Required to identify Western bird species by sight and sound
- Conducted vegetation surveys and data-entry
- Involved backcountry camping and hiking

VOLUNTEER EXPERIENCE

Pennsylvania Game Commission
Ruffed Grouse Surveys, State Gamelands 176   September 2007- 2008
- Conducted Ruffed Grouse flushing surveys to monitor population size
- Assisted in locating of drumming logs during spring drumming surveys

Deer Trapping, Wildlife Mgmt Unit 3C, Susquehanna County   February 2009
- Assembled and monitored lines of clover traps for White-tailed Deer
- Set up and manned rocket nets

The Pennsylvania State University   Spring 2009
   Teaching Intern
   - Assisted teaching assistant in conducting lab portion of Intro to Geography course
   - Answered student questions and provide assistance in using ArcMap software
   - Graded student oral presentations

National Park Service
   Salamander Study, Wind Cave National Park, SD   June 2009
   - Conducted nocturnal surveys for Tiger Salamanders to determine effects of pesticide use
   - Spotlighted for Black-footed Ferrets
   - Obtained microchip readings from sighted Ferrets

   Horned Lizard Study, Badlands National Park, SD   July 2009
   - Surveyed locations for presence of Horned Lizards
   - Road cruising for Prairie Rattlesnakes

   Garter Snake Genetics Study, Custer State Park, SD   June 2009
   - Conducted active searches for Garter Snakes
   - Took measurements and tail-clips for genetic analysis

Christmas Bird Count,   January 2010 & 2011
   Observer, Western Chester County Count Circle, PA
   - Conducted audio and visual surveys for local birds and recorded numbers
   - Led a survey party in 2011

James Cook University   March – June 2010
   Lab Assistant, Townsville, AU
   - Responsible for care and feeding of 100+ individually housed young Green-eyed Treefrogs and 20 adult treefrogs in terrariums.
   - Maintained two self-sustaining frog habitats
   - Monitored and maintained cricket populations

   Field Course, Charters Towers, AU   April 2010
   - Assisted in a general biodiversity study of privately owned cattle station
   - Included waterbird surveys, , mist –netting, trapping with harp, cage, Sherman and pit traps, frogging, spotlighting and conducting large mammal surveys by vehicle.

The Wildlife Society at Penn State   October 2010 - present
   Field Technician, University Park, PA
   - Trap Eastern Grey Squirrels using cage traps and fit them with radio collars
   - Use radio telemetry to identify locations of individuals and input information into a GIS
   - Field questions from the general public regarding trapping and collaring of squirrels

PROFESSIONAL DEVELOPMENT & AFFILIATIONS

The Wildlife Society at Penn State September 2007 – present
Treasurer
- Treasurer (2010 – 2011) Responsible for club funds including collecting dues, writing checks and managing the budget
- Professional Development Chair (2009-10) - in charge of coordinating speakers and workshops
- Fundraising and Recruitment Chair (2008-2009) – in charge of planning the annual game dinner fundraiser and promoting club activities to the university at large, designed club brochure
- Planning Committee Member (2008) - Northeastern Student Conclave hosted by Penn State
- Alumni Coordinator (2010) – founded the alumni group for the Penn State Wildlife Society. Responsible for database maintenance and alumni relations

School of Forest Resources Alumni Council
Undergraduate Representative April 2008 – present
- Board Member for the Penn State School of Forest Resources Alumni Council
- Represent student interests at biannual board meetings

The Wildlife Society September 2009 – present
Member, National and Pennsylvania Chapter
- Member of Spatial Ecology and Telemetry Working Group
- Attended National Conference in 2009 and 2010
- Presented in the Student Work-In-Progress Poster Session at 2010 National Conference
- Judged the Spatial Ecology and Telemetry Poster Session at 2010 National Conference
- Won best Undergraduate Poster at Delaware/Maryland State Chapter meeting in October 2010

School of Forest Resources Student Council
Member August 2010 - present
- Invited to represent the Wildlife Society as a student officer
- Represent interests and concerns of students and student organizations

Xi Sigma Pi November 2010 – present
Member, Eta Chapter
- National Forestry Honors Fraternity
- By invite only for upperclassmen with a GPA exceeding 3.0

Conservation Leaders for Tomorrow February 2011
Participant
- Participated in a three-day workshop on conservation education and hunting awareness
- Gained hands-on experience in safe handling and use of firearms
- Completed Hunter-Trapper Education Course
- Participated in a controlled pheasant hunt
- Learned to clean and prepare wild game meat

AWARDS & HONORS
- National Merit Scholarship Winner
- Schreyer Honors College Academic Excellence Scholarship (2007-2010)
- President's Freshman Award (2007-2008)
- John N. Adam Jr. Scholarship for Excellence in Agriculture 2008
- Harry Hayward Academic Excellence Scholarship 2009
- Oswald Scholarship 2009
- Robert T. Billin Scholarship 2009
- N.C. Harris Scholarship 2010
- Ruffed Grouse Society Annual Scholarship in Forest Resources 2010
- Dean's List Fall 2007, Spring 2008, Fall 2008, Spring 2009, Fall 2009
- Standard Bearer for Wildlife and Fisheries Science Major at Spring 2011 Commencement

SKILLS AND CERTIFICATIONS
- Working knowledge of ArcGIS, Adobe Photoshop, and database management
- Project WILD, Project Learning Tree, Project Aquatic WILD and
  Songbirds of PA Workshops
- 4WD and manual transmission
- NAUI Open Water and PADI Advanced SCUBA Certification
- 15+ Years of Horseback riding experience
- Trimble Certification
- Wilderness First Aid Certified (Nov 2010)
- CPR, AED & First Aid Certified (Feb 2011)
- Completed Hunter-Trapper Education course
- Wildlife Photography
- Ranked 5th kyu in Aikido